

SEPT.-OCT. '58

VOL. 1 • NO. 2

- Ginzton — Microwaves
- Southworth — Smith Chart
- Crandell-Dominick—Helical Phase Shifter
- FXR Company Profile
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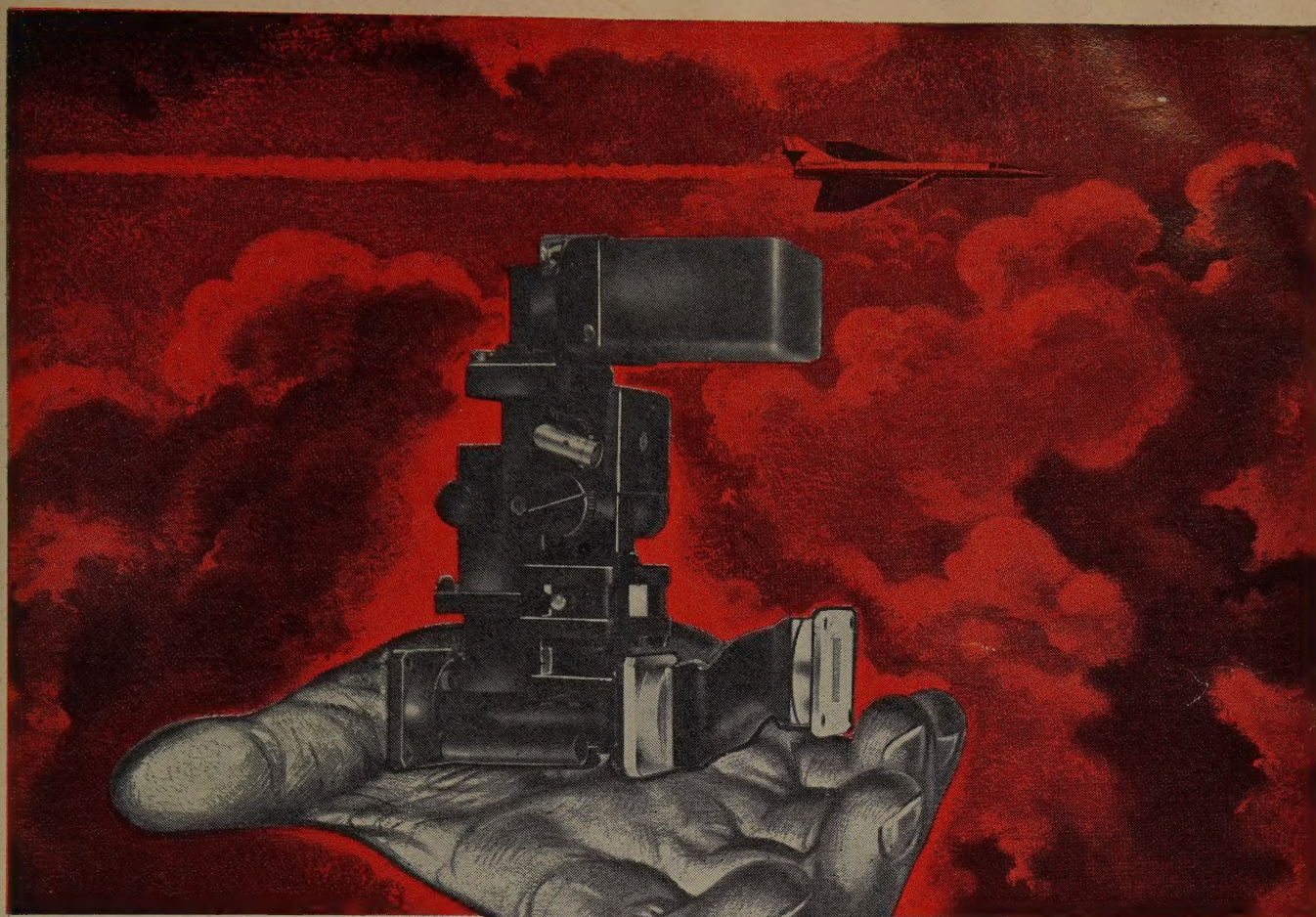
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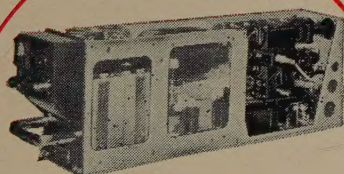
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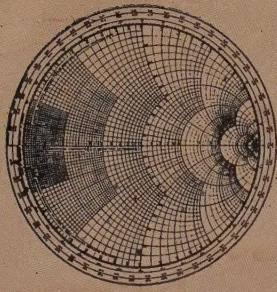
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# *the microwave journal*

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## COVER PICTURE

High power Stanford klystron. This tube, one of 22 used to power the Stanford "billion volt" linear accelerator, is capable of generating 30 million watts at a wavelength of 10 cm.

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WILLIAM A. BOURKE

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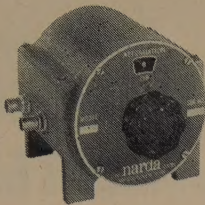
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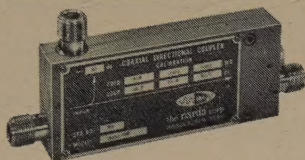
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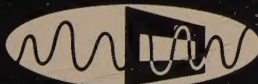


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# EDITORIAL

One of the most important policies of "the microwave journal" is to strive for balance of content without diluting the quality of the magazine. In each issue an effort will be made to include a variety of articles rather than articles similar in type or content.

A quick study of the results of our first reader response confirms the original beliefs of the editorial board regarding the need for variety in the magazine. The greatest response indicated a desire for tutorial or survey type papers. In the field of specialization, most of the reader response indicated a desire for papers on antennas. Following these two major groupings, the reader response was greatest in the fields of Ferrites, Solid State (especially parametric amplifiers) and microwave tubes (especially traveling wave types). There were a number of requests for papers on Measurements, Systems, Components, and news items. A happy note was that many readers wanted issues similar to Vol. I, No. 1.

In future issues there will be the usual engineering papers which will try to feature the three "D's" — designs, dimensions, and data. In addition, there will also be tutorial papers, survey papers, and summary papers.

The regular departments, including the biography, company profile, and business editorial, will also strive for balance between systems people and component people, between the East and the West, and between the large and the small.

In keeping with policy, the next issue will include the second part of Dr. Ginzton's article on "Microwaves," a guest editorial on antennas by Carl Sletten of AFCRC, a paper on masers by William From of Ewen Knight Corporation, and a paper on Ferrite Circulators by Dr. Peter Rizzi of Raytheon.

It may be well to stress here that the papers by From and Rizzi are excellent examples of the type of technical paper that we want to encourage for publication in our journal. They present to the engineer clear descriptions of the working of masers and ferrites, with a minimum of mathematics, and offer him facts and information that he can readily use. It is this type of paper that we expect to feature in each issue of "the microwave journal."

The biography will feature Royden Sanders, President of Sanders Associates, the company profile will describe Litton Industries, and the business editorial will be authored by Dave Ingalls, President of Airtron, Inc., a division of Litton Industries.

Your continued response, of course, is essential in keeping us aware as to the needs of the industry. It is our intention to present a balanced program of information to the engineer and his associates. We will include articles with a business flavor as well as information about people and companies.

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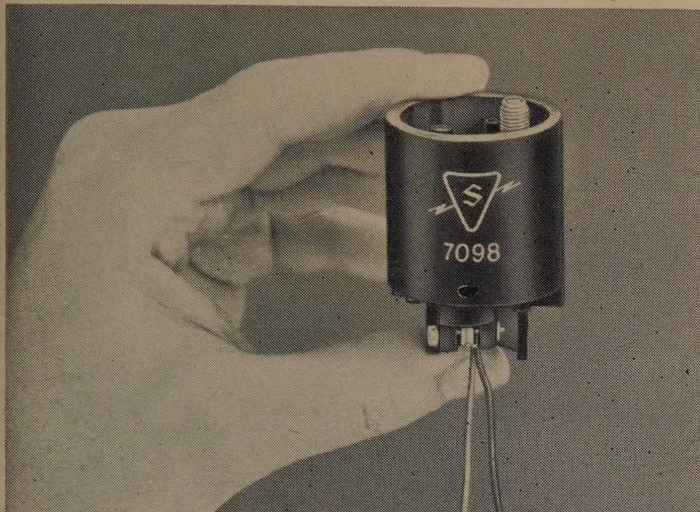
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# MICROWAVE AND SPECIAL TUBE

# NEWS

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## Six-Ounce Missile Magnetron Withstands 500 g

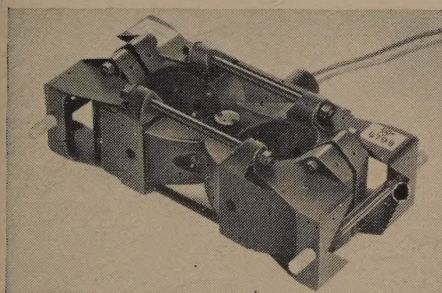


**Miniature magnetron, type 7098, for missile and beacon applications, meets extra severe environmental tests**

Palm-sized, mechanically tunable magnetron, designed to operate in the frequency range from 9300 to 9500 mc at 60 watts minimum peak power output, is now available from Sylvania. The rugged unit meets some of the military's toughest environmental requirements. Here are some of the tests that every 7098 must pass:

- Vibration of 10 to 60 cps at 0.08 inch total excursion and 60 to 2,000 cps at a constant acceleration of 15 g in each of three mutually perpendicular planes.
- Centrifuge test of 500 g acceleration.
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## New Ka Band Magnetrons specially designed for missile applications



**Light weight and extra ruggedness make Sylvania's new Ka band magnetrons ideal for high and low altitude pinpointing applications**

Four Ka Band magnetrons—types 6799, M 4064, M 4063 and M 4155 (ruggedized 5789), covering a power range from 20 KW to 100 KW, are now available from Sylvania. Particularly adaptable to high resolution applications, such as cloud finding, mapping and missile guidance, the three new types meet and surpass current missile vibration and shock requirements.

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|---------|-------------------|------------------|
| 6799    | 100 KW            | 33 lb            |
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| M 4155* | 40 KW             | 11 lb            |
| M 4063* | 20 KW             | 9 lb             |

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quency characteristics. Used principally in electronic counter-measure applications for barrage jamming, BWM's offer high reliability and require less associated circuitry and equipment than other power sources.

Today, 75 percent of the engineers and technicians employed at Sylvania's extensive magnetron facilities in Williamsport, Pa. are engaged in development work. For full particulars on how these outstanding facilities can help you, contact your Sylvania representative or write Sylvania direct.



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# On the Virtues of Separability



Marshall Pease

*Associate Editor*

## TUBES vs. INTRINSIC DEVICES

NATURE ABHORS A vacuum—at least in small pieces. Is it, then, sheer perversity that leads the engineer to build the fancy gadgets that are microwave tubes so that they must have vacuums within them? Does he like to work so hard for as nearly nothing as he can get? Or, if not perversity, is it only because of his ignorance of better methods?

These are questions that, with the advent of newer solid state devices, have acquired special meaning. They are worth some meditation.

There is, to be sure, the matter of ignorance—ignorance of how to do the job with intrinsic, non-vacuum devices; ignorance of how to design and to obtain the mediums with the properties he needs.

It seems to us, however, that there is more to be considered. The use of tubes is not simply the result of lack of knowledge of better methods. There are areas where the tube approach is, in fact, dictated by the basic logic of the situation. Tubes have advantages which, for some areas of interest, are of dominant importance. In the rush of enthusiasm for the new style devices, it would be dangerous to lose sight of what these advantages are.

To define our terms, we may observe that tubes have the distinguishing characteristic that the path of unobstructed flight of a carrier of energy—usually the electron—is at least of the same order of magnitude as that of the device itself. It may even be larger if, as in the magnetron, there is a force present to curve the trajectories around. More usually, it is somewhat smaller. But in any case, it is physically large.

The converse occurs in what we shall call the “intrinsic” devices. These include masers, solid-state parametric amplifiers, transistors, plasma devices, and so on. These are all characterized by the fact that the mean free path of a carrier of energy is short, and often microscopic. This is true, whether the carrier is an electron, a “hole”, a photon, or some more abstract entity. It applies whether the obstructing entity is a gas ion or molecule, a lattice point or discontinuity, or whatever. If the length of unobstructed flight is short, then interaction must depend on the intrinsic properties of the medium—i.e., those that depend

on kind, and not on size or shape. It is for this reason that the term “intrinsic” device has been used.

The classification of devices into these two groups ignores the fact that there are some intermediate cases. It ignores also the fact that intrinsic devices and tubes are sometimes used in ways that do not involve the interaction of the medium with a stream of energy carriers, or involve it only in an awkward sort of manner, as, for example, a power rectifier. While these complications do exist, we shall simply label them as being outside the scope of our meditation, and ignore them.

From these definitions, then, we see immediately one very fundamental difference between the two classes of devices. For, when the mean free path is very short, it is obvious that we can speak of velocity only as a statistical function. We cannot conceivably control either the direction or the magnitude of the velocity of a single carrier at any given instant or location. We can control only the average value, and can speak with meaning only of the average behavior of a given carrier of energy. We do not have and we cannot have control of its detailed behavior.

To say that we have exact control in a tube is, of course, an idealization. There are many things that happen in a tube that we cannot control as we would wish, and these things have effects that are often very annoying. Nevertheless, it is still true that we do have trajectorial control in a way that, by definition, is not conceivable in an intrinsic device.

What does this mean? Obviously, it does not mean that a tube is noise free. Noise is the result of the microscopically detailed structure of the ensemble that is the beam; the control we speak of here is a microscopic one. Its connection with the noise of a tube is indirect, and little different in principle from the comparable relation for an intrinsic device.

The principle significance of this element of control is, it seems to us, in the separability of function that it makes possible. The electron beam can be generated at one end of the tube, tied in a bow knot, and then sent to where we want it to go. We can, in the meantime, make it flow gently like a rippling brook, or rip along like water from a firehose. We can send it to the precise

location where we want it, and keep it out of where we do not want it.

There is separation, also, of the beam and circuit. In a tube, these are completely different things; the one made in the machine shop, the other in the mind of the engineer. In an intrinsic device, this is not so. There is no clearly defined circuit, except what is hung on the outside. There are the lattice points of a crystal, the positive ions of a plasma, the abstract energy levels of a maser, or the spin levels of a ferrite. These have, more or less, the function of the tubist's circuit as providing the interaction environment. But they are also part of the environment in which the "beam", or flowing carriers, exists. Usually, also, they are both the source of said beam, and its ultimate sink. It is only in a tube that these separate functions are handled by separated structures.

So what good is it? Separability is nice; but it better buy us something, or we will ditch it.

There are several things that we might think about here, in answer to this question. Power density is one of them. A beam that is generated in one place and then transported elsewhere can have enormous power pumped

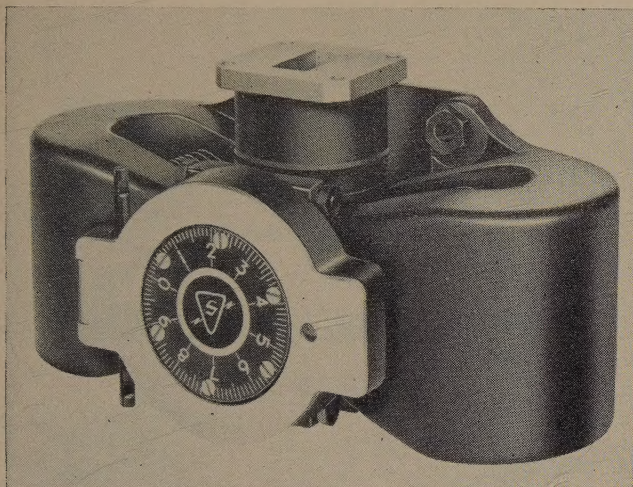


Figure 1 — A Typical Device X-band Tunable Magnetron

into it along the way. It can be accelerated over a relatively huge distance along the route, so that energy per electron is increased by many orders of magnitude. The whole beam can be compressed. We can end up with a power flow in the beam, before interaction, amounting to hundreds of kilowatts or megawatts per square centimeter.

Given such a beam, the separation of function lets us use it. We can, if we wish, distribute the interaction over a long distance, letting it occur gradually and slowly. Any dissipation that may result from the interaction can be spread out over a wide area, and disposed of as convenient. And finally, because the collector function is separate, the beam can be terminated in a suitably designed power sink.

We would not dare to say what is the ultimate quantitative limit of power density in an intrinsic device, but we can expect it to be far lower than is possible in tubes. Since this is a logical consequence of the separability of function that is obtained in tubes, we believe this difference to be fundamental.

the microwave journal for September/October, 1958

We may also think in terms of the degree of flexibility of the operation of a given device. In a tube, where the circuit is separate, we may design it so that its interaction characteristics — frequency vs. voltage, etc. — have any desired shape that is consistent with physical realizability and our own ingenuity. If this makes the interaction slow, then we can simply stretch the whole thing out until we have brought back the total interaction that we need.

An intrinsic oscillator or amplifier, on the other hand, depends on the interaction of individual microscopic sites, (ions, lattice points, etc.) with the electron or other carrier. This interaction must occur in a very short distance, hence it must be relatively strong. On the other hand, for coherent operation, the sites must be coupled together. Since this coupling must extend over many intermolecular, or inter-ionic distances, it will tend to be very weak. Furthermore, since the beam in such a device is, as we have said, essentially incoherent, it must be prevented from reflecting this incoherence back into the interacting sites.

These requirements, which are, to a large extent, contradictory, pose quite a problem. Two types of solutions to this problem have been used, each of which has its own limitations.

One solution depends upon the use of those intrinsic parameters that are, by their very nature, highly selective. The two-level gas maser may be cited as an example of this. The interaction is very highly resonant, and therefore confined to an extremely narrow band of frequencies. If this is what is needed, all well and good. Lack of flexibility can, in proper circumstances, be a virtue. But lack of flexibility is there. Only those parameters, such as input signal level, which are not involved in the resonance condition, can be permitted to vary.

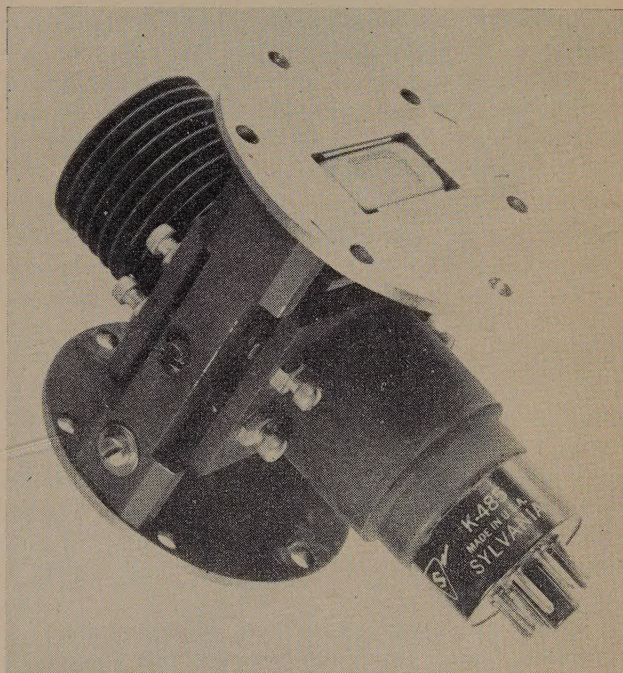


Figure 2 — The K-485, a Klystron Amplifier, operates in the 6800-7125 kmc frequency range.

The other solution depends on coupling the sites through their external environment. This may be in a resonant cavity, with a "pumping" r-f field, or with an applied magnetic field. To do this, however, brings back some of the problems of size, tolerance, etc., of tubes and hence

represents an immediate partial sacrifice of the virtues of an intrinsic device.

This solution also involves a rather extreme sacrifice of efficiency and power. This has certainly been true as a practical matter. We believe it is also, to some extent at least, a fundamental effect resulting from the logic of the situation itself. This follows from the nature of the job that is required. The coupling of the site to the carrier must, as we have said, be strong. Too, we must prevent the back coupling from reflecting the incoherence of the stream of carriers back into the sites. This back coupling must be over-ridden by the environmental control. This control, then, must be strong compared to the density of the carriers. Hence the low efficiency and power output.

We have furthermore the limitations imposed by the necessity of strong coupling between the site and the carrier, implied by the short time and distance over which the full interaction must be obtained. In general, this can be obtained only by some sort of resonance method, which then implies a severe bandwidth limitation.

We conclude, then, that an intrinsic device tends to be limited in bandwidth, and, usually, in power and efficiency. Where other factors may be of dominant concern, their loss may be inconsequential; but if we consider the whole range of possible applications, it does limit the applicability of intrinsic devices.

The separation of function in a tube leads to the opposite situation. Since the interaction may be distributed over a large distance, it may be accomplished with a very weak field. While, as we push to the highest powers, or to the smallest size, or to some other limit, we do find the beam affecting the circuit, this tendency is far weaker and much more easily held to an allowable limit. Also, we do not need high energy storage to achieve strong interaction, or, in fact, any energy storage. We may use it if it is advantageous to do so, as we do in a magnetron or klystron, but it is not a necessary condition to effective interaction. If we do use it, we do so because we want to; not because we are forced to.

We can, then, make tubes with any characteristics we desire, if we are smart enough. If we want an amplifier, we can, except for purely technological difficulties, build one with an infinitely wide band, any reasonable gain, and with a substantial power density. Or, if we want an oscillator, we can have reasonable power density and voltage tunability over a wide range. We can also build either an oscillator or amplifier, useful over a reasonably wide range, that delivers relatively enormous powers at high efficiency.

There is still another consequence of separability that, while not as ultimately binding, is still of great practical importance. As any good tube designer knows, a large part of tube development is plagiarism. Legitimately so, but still plagiarism. He will borrow a gun from this tube, modify the output used in that one, adjust the delay line parameters from a third, and otherwise use whatever he can lay his hands on and adapt it to his own special needs. He does this with good judgment, if he is smart, and, it may be, with considerable creativeness in the process. Nevertheless, development always starts from where history stops.

The significance of separability in this regard is that it opens the way to piecemeal borrowing. The designer of intrinsic devices also uses history, but he cannot take over

pieces of designs. He takes over physical principles and insights. He extrapolates history, trying to guess how to change previous designs and formulations in order to find a medium that will fill his need; but he cannot hybridize, in the same sense as does the tube designer.

This means that it will usually be easier to find an answer to a new need through the tube approach. This is true even where ultimately the best answer will be an intrinsic device. The first answer is most likely to be a tube, unless because of abnormally high frequency or the like, the whole problem is completely beyond what is practical in a tube at all. If, then, the job is important enough to justify the additional research and development, the tube may ultimately be obsoleted by an intrinsic device. In the meantime, however, it will have done an important job.

All of this foregoing, of course, does not mean that intrinsic devices are a snare and a delusion. The past achievements in this field, and its indicated capabilities for the future, are too great to permit any such foolhardy conclusion. It does mean, however, that these achievements and capabilities have not obsoleted the tube approach. Nor, if our logic is correct, will they. Intrinsic

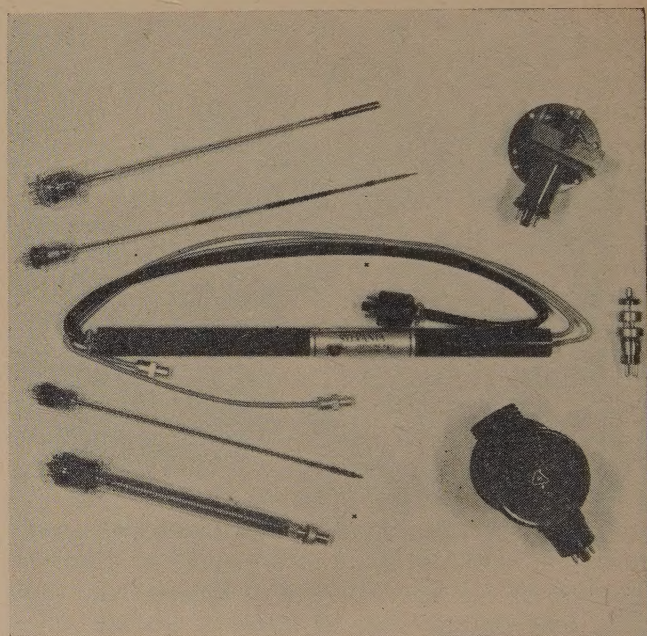


Figure 3—Traveling wave tubes and components; other devices.

devices are limited, and so also is the rate of their development. There are needs for which they are the ideal answer, but there are other need which they do not meet; and even where they are the answer, it is an answer that is difficult to come by.

So, it is not merely perversity that leads us to build elaborate vacuum tubes. It is, rather, the fact that the simplicity of a solid state device is deceptive. It is simple in final form, yes; it is simple because a multiplicity of functions are combined in a single element, the medium itself. The structure of a tube is, to be sure, complex; but this complexity is because of the physical separation of function within the device. This implies a simplicity of concept and design and design effort at any given point within the structure. Each approach has its field, and the fields overlap, but neither shows any prospect of obsoleting, in any total fashion, the other.

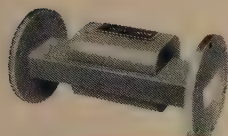
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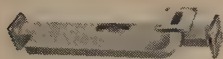
WAVEGUIDE ISOLATORS

See Catalog Page A-21



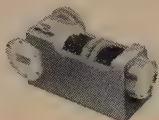
ROTARY STANDING WAVE DETECTOR

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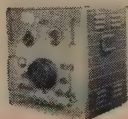
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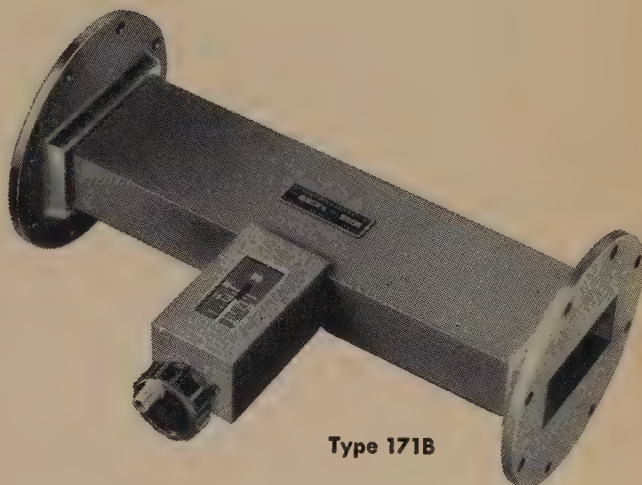
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Type 171B

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For complete specifications, see page A-17 of the NEW PRD Catalog.

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**POLYTECHNIC RESEARCH & DEVELOPMENT CO., INC.**  
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# PUBLISHER'S EDITORIAL

Volume I, Number 1 of "the microwave journal" is now history and this issue is being assessed by the industry for the continuance of quality. The efforts of our Technical Editor and the contributions of our Editorial Associates and Guest Contributors have been submitted. We think these people are fulfilling an area of need and are continuing a flow of practical information into the microwave industry.

The response to our first issue was favorable. A large number of letters were received commenting on the format and content of the "journal." We wish to acknowledge and thank those who wrote and were so flattering in their comments.

For the remainder of 1958, "the microwave journal" will be published bi-monthly. Starting in January, 1959, the "journal" will be issued on a regular monthly basis.

The requests for Volume I, Number 1 were so heavy we regret we could not fulfill all of them. If you did not receive a copy, be assured that your name was placed on the list for future mailings.

The Editor has an interesting issue planned for November/December. The technical articles are in the practical areas of masers and ferrites.

Due to the interest generated in the industry by mergers, the Litton-Airtron Profile should be of considerable interest.

Mr. Dave Ingalls will comment on his recent trip to Russia in the business editorial and he provides another point of view about this serious competitive threat.

One of the objectives of this publication will be to open the channels of communication for the dissemination of technical information that will be useful to the industry. The need for practical information that will be "Saving Your Time" has been made apparent. The Editor with the Associate Editors, because they are a part of the industry, assist in making this publication an effective engineering tool.

We wish to thank those contributors who assisted us in the formation of this "journal." Their willingness to contribute papers indicates their recognition of the need in this field.

Dr. George Southworth has summed up the matter in his letter to "the microwave journal" in the first issue. He points out the "great need at the moment for tutorial papers particularly in the field of microwaves. To many people this field is still very strange. Much needs to be said about basic principles and much needs to be said about how the many new gadgets that come from these principles really work. Above all much simplification is needed."

We wish to emphasize that "the microwave journal" is primarily a technical publication. However, there will be news of companies and people who have made contributions to the microwave industry.



## PRD ANNOUNCES NEW APPOINTMENT

Appointment of Moe Wind as Assistant Sales Manager is announced by Herbert Finke, general manager of Polytechnic Research & Development Co., Inc., Brooklyn, New York. A member of the PRD staff since 1956, Mr. Wind was formerly Chief Applications Engineer.

Formerly a member of the research staff of The Polytechnic Institute of Brooklyn, he is a contributing author to and co-editor of "Handbook of Microwave Measurements" and the editor of and contributing author to "Handbook of Electronic Measurements," published by the Institute.

In addition to memberships in the Institute of Radio Engineers, Sigma Xi, Tau Beta Pi and Eta Kappa Nu, Mr. Wind has served on the executive committees of the Basic Science Division (New York Section) of the American Institute of Electrical Engineers, and the New York Sections of the Institute of Radio Engineers and the Professional Group on Microwave Theory and Techniques.

Mr. Wind received a degree of B.E.E. in 1948 from Polytechnic Institute and an M.E.E. from Polytech in 1950.

## De MORNAY-BONARDI APPOINTS NEW REP. IN NEW ENGLAND

De Mornay-Bonardi, Pasadena, Calif., manufacturers of microwave test instruments, has appointed Instrument Dynamics, Inc., Wakefield, Mass. as their new sales and engineering representatives in New England. The rep. firm will handle the entire De Mornay-Bonardi line of instruments, including new ultramicrowave test equipment.



### PEARSON NAMED DIRECTOR OF MFG., AMF GOV'T PRODUCTS GROUP

Robert W. Pearson, formerly deputy general manager for operations at American Machine & Foundry Company's Electronics Division in Boston, has been appointed Director of Manufacturing for AMF's Government Products Group, it was announced by Fred K. Powell, Jr., vice president and Government Products Group executive.

Before joining AMF in 1948, Mr. Pearson was with RCA at Camden, New Jersey.

Prior to that he was superintendent of the Radio Division of Federal Television and Radio Corporation from 1946 to 1948. From 1937 to 1942 he was an industrial electronic control engineer with Westinghouse Electric Company, Pittsburgh, Pennsylvania.

During World War II, he served with the Signal Corps in Washington, D.C. and Fort Monmouth, New Jersey. He held the rank of Lt. Colonel.

Mr. Pearson was graduated from Drexel Institute, receiving his B.S. degree in 1935. He earned an M.S. degree in Electrical Engineering in 1941 at the University of Pittsburgh.

He is a member of the IRE and the American Mathematical Society and was formerly secretary of the Philadelphia Chapter of the Armed Forces Communications Association. He holds a Reserve commission as Lt. Colonel in the Signal Corps.

Mr. Pearson is married and the father of three daughters. He and his family reside at 105 Ridge Road, Erlton, New Jersey.

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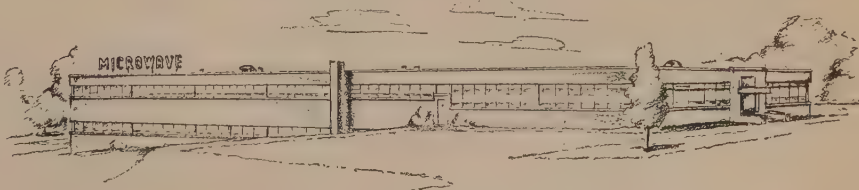
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## BIOGRAPHY

### RUSSEL H. AND

**A**LTHOUGH ELECTRONICS as an art is young, from the beginning of the industry there have been stories of daring and success. Predominant in such annals is the Varian success story, beginning as it did with the invention and development of the klystron by Russell Harrison Varian and his brother Sigurd Furgus Varian.

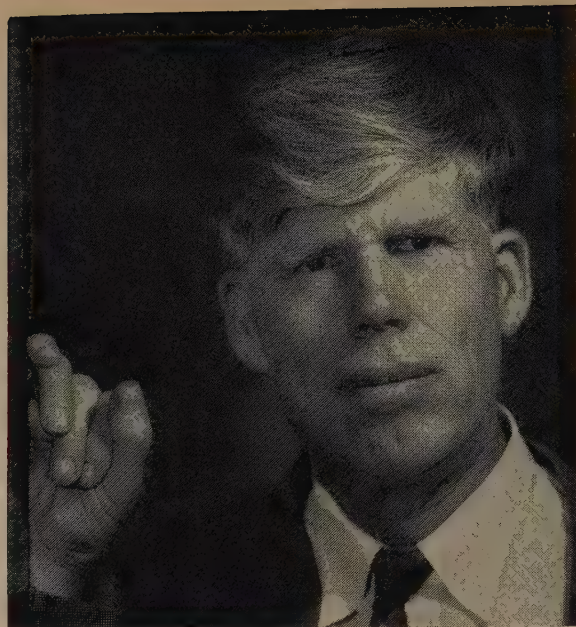
The lives of the Varian brothers, world famous for their invention of the revolutionary microwave tube known as the klystron, overlap on so many fronts it is impossible to consider their biographies separately. Both are highly inventive; Russell more in the realm of broad concepts, Sigurd more in the realm of methods and devices to make the concepts work.

Their parents, Dublin born John Osborn Varian and Australian born Agnes Dixon Varian, migrated from Ireland to California before the turn of the century but soon moved on to Washington, D.C. to join an uncle, John Osborn, inventor of lithographic printing and blueprinting process who had preceded them from Ireland. It was in Washington, D.C. that Russell Harrison Varian was born, April 24, 1898.

When Sigurd was born, May 4, 1901, the family was living in Syracuse, New York. A year later they moved to Palo Alto, California where Russell and Sigurd attended grammar school. High school days were spent in Arroyo Grande, California.

Russell worked his way through Stanford University, performing odd jobs in the laboratories and helping professors with their lawns and gardens. He was graduated with an A.B. degree in Physics in 1925, obtained his Master's degree in 1927, and continued to do graduate work in physics until 1929 when he went to work in the geophysical laboratory of the Humble Oil Company in Texas as a research physicist. In 1930 he joined the Farnsworth Radio and Television Corporation in San Francisco as a research engineer where he was associated with Philo T. Farnsworth in the pioneering of television until 1933.

High school over, Sigurd worked a year for the California Edison Company as a lineman in the High Sierras before enrolling at the Polytechnic Institute in San Luis Obispo. "Flying Fever" was prevalent among young men who had not been old enough to serve in World War I and Sigurd caught the bug. He used his next earnings to buy half interest in a wartime Jenny and start a flying school in the desert near Indio. Several barnstorming years later he joined Pan American Airways, and was one of the first pilots sent to Mexico to inaugurate service there and in Central America. Between 1929 and 1935, as flight captain for Pan American, he flew between Brownsville, Texas, and Panama. In 1929 Sigurd married Winifred Hogg, daughter of the British consul in Vera Cruz, Mexico. They have two children, Lorna Dixon Van Linge, born April 1, 1932 and John Osborn Varian, born Septem-



Russell Harrison Varian, Chairman of the Board,  
Varian Associates

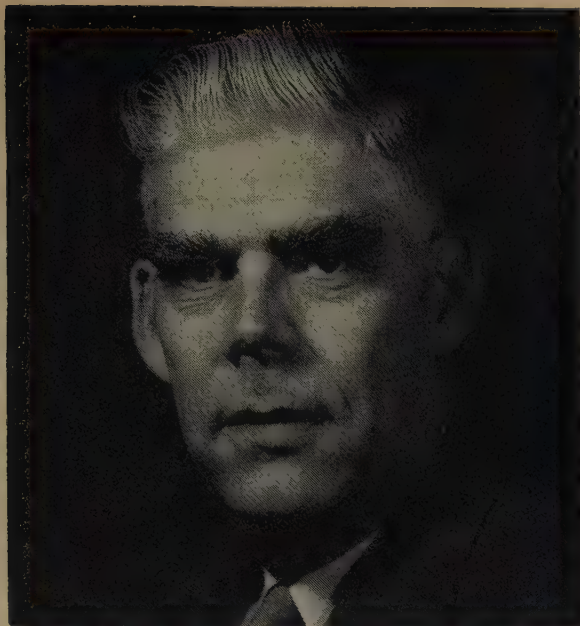
ber 7, 1935. A granddaughter, Vicki Van Linge, was born November 30, 1956.

As an airline pilot operating under hazardous conditions, Sigurd was faced with an acute need for improved flying aids, particularly for blind-landing. And with all signs pointing to another war, he realized the military need was even more urgent. Just as there was no reliable way to land pilots safely in bad weather, or at night, there also was no way to detect the presence of a hidden enemy in the air. Although it was certain the radio solution of both problems was the same, there was no instrument capable of generating with adequate power and frequency purity at the very high frequencies required.

By 1934, Russell was back at Stanford working toward a Ph.D. but keeping in touch with Sigurd by letters. Topics ranged from the laboratory they dreamed of establishing together to discussions of many ideas on invention. The quest for counter measures against the threat of Hitler's growing air force was the most recurrent subject and ultimately led to the invention of the klystron. The origin of the klystron is best told by Russell Varian himself:

"At this time Hitler was beginning to show his strength and Sig was very much concerned about this threat and was groping for an answer.

"We considered building radars—the name had not been invented at that time—but there was no source of centimeter waves. During this period I was in correspondence with Dr. W. W. Hansen of Stanford University about a project we started together, the possibility of using a resonant concentric line as a source of high voltage for producing X-rays. After I left Stanford, Dr. Hansen continued work in this field and later calculated the resonant behavior of a hollow sphere and of a hollow right circular cylinder. These turned out to have much higher resonance than any of the previous types of resonators. If we were to make radar, I knew we had to get into the microwave region. I was well aware of the limitation placed on generation of radio frequencies by conventional methods, which was imposed by the declining efficiency of the resonant



Sigurd Furgus Varian, Vice Chairman of the Board,  
Varian Associates

## SIGURD F. VARIAN

### *inventors of the Klystron*

"Design started almost immediately. Hansen's knowledge of the behavior of hollow resonators being very important in the design. In a little over a week there appeared in my notebook a klystron design which looked very much like the cross-section of present day klystrons. The next job was to build it and this is where Sig's great contributions came in. In an amazingly short time we had a klystron actually operating under a bell jar. We had spent about \$50 of the \$100 appropriated by the University, mostly for condensers for our power supply. At this point we were practically out of money and had to find more support for the project.

"Sig made use of some of his flying contacts which carried him through CAA to the Army and Navy. Considerable interest was shown by all three branches, but at that time none of them had any personnel on the Pacific Coast capable of appraising the development. We received a phone call from the CAA informing us that Dr. Hugh Willis of Sperry Gyroscope Company was very interested in the development.

"We had a hurried consultation as to whether we should at this point bring in what was to us a large corporation, and ended by deciding that we had better take a chance and we ended by taking support from the Sperry Gyroscope Company.

"We worked for a short time in laboratories on the San Francisco Peninsula and then were moved to the Sperry Laboratories at Garden City, New York, where Sig and I, and Dr. Hansen part-time, spent the war years developing klystrons.

"Two major components of World War II radar which were new were the klystron and the magnetron developed by the British. There were three separate points in World War II which were turning points depending on radar. If the British had not developed their early long range, low frequency radars just in time, the German Blitz against England would have been successful and the war would have been over. These radars, however, did not use klystrons. After daylight bombing became too costly to the Germans, they turned to night bombing, and again there was no defense. But the British got their first airborne radars into operation just in time to stave off defeat. These radars did use klystrons. After the air blitz against England had failed, the Germans turned to the use of submarines. These were so effective that England would soon have been starved into submission, but the English adapted their airborne radar to search for submarines while they were surfaced at night and succeeded in pretty effectively wiping out the German submarine fleet."

circuit attached to the tube. Hansen's work seemed to be a solution to this problem. I was less aware of the problem produced by flight time of electrons in a conventional radio tube, but became very aware of it shortly afterwards.

"My brother and I went to Stanford and found Dr. Hansen very receptive to the idea of embarking on this microwave project. We also found Dr. Webster, the head of the Physics Department, very cooperative in getting it going. He arranged with Dr. Wilbur, President of the University, that Sig and I would work as research associates in the Physics Department, at no salary, and that the University would contribute \$100 for materials and supplies. The department shops and stock piles were also at our disposal.

"We as yet had no idea of how to cause a stream of electrons to supply energy to a resonant circuit no matter how efficient the resonant circuit might be. However we came to two fundamental conclusions very early in the work. One was that we must find a mode of operation that was much less sensitive to the detrimental effect of flight time of the electrons, and the other was that the resonant cavity itself must act directly on the electrons and not be merely coupled to the electron tube as in conventional tubes. We considered various types of sweeping beam tubes and resonant Larmor frequency tubes. Some of them looked possible but very difficult.

"Up to this time I had 22 different schemes in my notebook. At this point I started to develop a systematic means of classification of all the ideas that had been developed to date. The object of this work was to be able to determine whether or not we had really covered the field and had not overlooked some good possibility. While I was working on this classification I suddenly thought of the velocity grouping principle of the klystron and I immediately recognized it as something very interesting indeed. An interesting side-light is that the velocity grouping principle did not fit my classification scheme at all and I think that the idea was the result of an unconscious effort to test the validity of the classification scheme that I had devised.



Varian Associates "Big Three" in conference: Russell Varian (left), Chairman of the Board; H. Myrl Stearns (center), President; and Vice Chairman of the Board, Sigurd Varian.

Overnight, the Varian brothers became internationally famous for their epoch-making discovery in microwave communications and the klystron's possibilities were immediately recognized as of the highest importance for aviation, navigation at sea, telephony, television, and other branches of communication. The directability and reflectability of microwaves afforded vast potentialities for industrial as well as military use of radar art.

In 1948, the first chapter of another dream began to materialize. With six associates and pooled resources of \$22,000, Varian Associates was incorporated for the purpose of conducting research and manufacturing in electronics and other physical sciences. First scene of operations was a 1200 square foot rented building in San Carlos, California. A brief ten years later, Varian facilities on a 33 acre lease site in Stanford Industrial Associates was housed in a multimillion dollar plant Park, totaling 265,000 square feet of working space. With assets of \$15,000,000 and sales and profits reaching an all time high, the company is sponsoring a program of long range planning, broadening of product lines, new avenues of diversification and allotment of more and more money for research and development.

Among Russell Varian's more than 100 patents issued or pending in the microwave and applied physics fields is the proton free precession magnetometer. Continuing company research and development of the magnetometer has produced a minified version for an American earth satellite, the Varian Aerobee Rocket Magnetometer and the M-49 portable magnetometer.

In recognition of their work in the development of the klystron and the consequent opening up of hitherto unexplored fields in communications and applications, Russell and Sigurd Varian were awarded the John Price Wetherill Medal of the Franklin Institute in Philadelphia.

Russell holds an honorary degree of Doctor of Engineering from the Polytechnic Institute of Brooklyn, is a Fellow of the IRE and of the California Academy of Sciences, a member of the American Physical Society, the American Association for the Advancement of Science and Sigma Xi. He is a former member of the Board of Directors of the West Coast Electronic Manufacturers Association and a member of the Sierra Club.

In 1947 Russell Varian and Dorothy Hill were married. They have two children; Charles John, born February 28, 1949 and Susan Aileen, born October 28, 1951. Mrs. Varian was closely associated with her husband in the founding of the firm of Varian Associates and was a member of the board of directors and treasurer for the company until her retirement in 1951. By a previous marriage, Dr. Varian has a son, George Russell Varian, born April 22, 1943. Mountaineering, horticulture and nutrition, Irish history and folklore, and children, comprise Russell's outside interests. Personal philosophies are reflected in the articles he regularly contributes to the Varian company magazine.

Sigurd also holds numerous patents and is co-inventor of several pending or issued patents in microwave and other techniques. He is a member of Sigma Xi and a member of the Airline Pilot Association. His engineering interests occupy him as much recreationally as professionally. In his well equipped home laboratory-shop he is constantly devising "gadgetry" of all kinds, from a precision high speed drill press to a new system of pumps, filters, and heaters for his swimming pool.

Sigurd pilots his own plane in the frequent jaunts he and his wife take about the country. His wife Winnie, has carefully saved letters, clippings, photos and other pertinent data about the Varian brothers joint enterprise, and recently had the accumulation bound in several volumes.

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| Characteristics         | Two (2) Section Resonator          | Three (3) Section Resonator        | Four (4) Section Resonator         |
|-------------------------|------------------------------------|------------------------------------|------------------------------------|
| Model No.               | 27-BW                              | 27-CW                              | 27-DW                              |
| Type of Resonator       | TE <sub>101</sub> mode rectangular | TE <sub>101</sub> mode rectangular | TE <sub>101</sub> mode rectangular |
| Tuning Range            | 2700-3150 MCS                      | 2700-2950 MCS                      | 2700-2900 MCS                      |
| 3 db Bandwidth          | 4.5-6.5 MCS                        | 4.5-5.5 MCS                        | 4.5-5.5 MCS                        |
| Max 30 db Bandwidth     | 36 MCS                             | 18 MCS                             | 13 MCS                             |
| Max Insertion Loss      | .9 db                              | 1.3 db                             | 1.8 db                             |
| Price                   | \$400.00                           | \$535.00                           | \$670.00                           |
| Model No.               | 27-BC                              | 27-CC                              | 27-DC                              |
| Type of Resonant Cavity | $\lambda/4$ coax                   | $\lambda/4$ coax                   | $\lambda/4$ coax                   |
| Tuning Range            | 2700-3200 MCS                      | 2700-3100 MCS                      | 2700-2950 MCS                      |
| 3 db Bandwidth          | 8-11 MCS                           | 8-10 MCS                           | 8-9 MCS                            |
| Max 30 db Bandwidth     | 60 MCS                             | 32 MCS                             | 21 MCS                             |
| Max Insertion Loss      | 1.6 db                             | 2.4 db                             | 3.2 db                             |
| Price                   | \$350.00                           | \$475.00                           | \$600.00                           |

## C BAND FILTERS

| Characteristics     | Two (2) Section Resonator | Three (3) Section Resonator | Four (4) Section Resonator |
|---------------------|---------------------------|-----------------------------|----------------------------|
| Model No.           | 54-BC                     | 54-CC                       | 54-DC                      |
| Type of Resonator   | $\lambda/4$ coax          | $\lambda/4$ coax            | $\lambda/4$ coax           |
| Tuning Range        | 5400-5950 MCS             | 5400-5950 MCS               | 5400-5750 MCS              |
| 3 db Bandwidth      | 8-11 MCS                  | 8-10 MCS                    | 8-9 MCS                    |
| Max 30 db Bandwidth | 60 MCS                    | 32 MCS                      | 21 MCS                     |
| Max Insertion Loss  | 2 db                      | 3 db                        | 4 db                       |
| Price               | \$360.00                  | \$485.00                    | \$610.00                   |

## L BAND FILTERS

| Characteristics         | Two (2) Section Resonator | Three (3) Section Resonator | Four (4) Section Resonator |
|-------------------------|---------------------------|-----------------------------|----------------------------|
| Model No.               | 96-BC                     | 96-CC                       | 96-DC                      |
| Type of Resonant Cavity | $\lambda/4$ coax          | $\lambda/4$ coax            | $\lambda/4$ coax           |
| Tuning Range            | 960-1150 MCS              | 960-1100 MCS                | 960-1050 MCS               |
| 3 db Bandwidth          | 8-11 MCS                  | 8-10 MCS                    | 8-9 MCS                    |
| Max 30 db Bandwidth     | 60 MCS                    | 32 MCS                      | 21 MCS                     |
| Max Insertion Loss      | 1.2 db                    | 1.8 db                      | 2.5 db                     |
| Price                   | \$370.00                  | \$495.00                    | \$620.00                   |

## X BAND FILTERS

| Characteristics         | Two (2) Section Resonator          | Three (3) Section Resonator        | Four (4) Section Resonator         |
|-------------------------|------------------------------------|------------------------------------|------------------------------------|
| Model No.               | 75-BW                              | 75-CW                              | 75-DW                              |
| Type of Resonant Cavity | TE <sub>111</sub> mode cylindrical | TE <sub>111</sub> mode cylindrical | TE <sub>111</sub> mode cylindrical |
| Tuning Range            | 7500-8500 MCS                      | 7500-8250 MCS                      | 7500-8000 MCS                      |
| 3 db Bandwidth          | 8-11 MCS                           | 8-10 MCS                           | 8-9 MCS                            |
| Max 30 db Bandwidth     | 60 MCS                             | 32 MCS                             | 21 MCS                             |
| Max Insertion Loss      | 1.5 db                             | 2.5 db                             | 3.5 db                             |
| Price                   | \$475.00                           | \$625.00                           | \$775.00                           |
| Model No.               | 85-BW                              | 85-CW                              | 85-DW                              |
| Type of Resonant Cavity | TE <sub>111</sub> mode cylindrical | TE <sub>111</sub> mode cylindrical | TE <sub>111</sub> mode cylindrical |
| Tuning Range            | 8500-9600 MCS                      | 8500-9300 MCS                      | 8500-9000 MCS                      |
| 3 db Bandwidth          | 8-11 MCS                           | 8-10 MCS                           | 8-9 MCS                            |
| Max 30 db Bandwidth     | 60 MCS                             | 32 MCS                             | 21 MCS                             |
| Max Insertion Loss      | 1.5 db                             | 2.5 db                             | 3.5 db                             |
| Price                   | \$475.00                           | \$625.00                           | \$775.00                           |

All of the above filters have Max VSWR of 1.5, and either a single shaft or counter dial for Tuning Control. Depending upon mode of operation, units are supplied with either Type N Connectors or Waveguide flanges.

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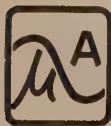
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## Letters to the Editor

We invite comments and letters to the editor each month. We are appreciative of these unsolicited letters that arrived and were instrumental in helping us form our decision to start "the microwave journal."

. . . I was delighted with your first issue of "the microwave journal," and if you can keep up the quality that is evident here, you will do a real service to the profession. Congratulations and sincere good wishes on this great contribution to the literature on microwaves.

WALTER J. SEELEY  
Dean, Duke University  
College of Engineering

. . . You are to be congratulated for your initiative in this endeavor, it is something the profession has needed for some time.

HOMER G. HOLZGRAFE  
Head, Microwave Laboratory  
Raytheon Mfg. Co.  
Oxnard, Calif.

. . . We have received Volume I No. 1 of your new publication, "the microwave journal," and find it extremely interesting, and pertinent to the work being done in our laboratories. . . . By sending the magazine to the Technical Library, it will be drawn to the attention of a number of our research scientists.

HAROLD S. SHARP  
Chief Librarian  
ITT Laboratories  
Ft. Wayne, Indiana

. . . Your first issue was received most favorably here. . . . It is my opinion that this publication will find a long-existent gap. . . .

F. NATTON RODDA  
Research Engineer  
Lockheed Aircraft Corp.

. . . I have had the privilege of reviewing your first issue of "the microwave journal" and found it very interesting indeed. . . . My work and the work of my group is concerned in large part with the evaluation and application of new solid-state devices at microwave frequencies, so that much of your information is extremely pertinent. . . .

JAMES B. ANGELL, Sc.D.  
Manager, Solid-State Research  
Philco Corp., Philadelphia, Pa.

(Continued on page 33)



## DR. ARTHUR UHLIR JOINS MICROWAVE ASSOCIATES, INC.

Microwave Associates, Inc. announces the appointment of Dr. Arthur Uhlir, Jr. as Director of Semiconductor Research and Development. Dr. Uhlir will head Microwave's expanding activities in the development of new semiconductor devices, including variable capacitance microwave diodes (also known as parametric amplifier diodes; mavar diodes; and varactors), microwave silicon mixer and video diodes, and silicon power rectifiers.

Until recently Dr. Uhlir was closely associated with the group that developed the microwave varactor at the Bell Telephone Laboratories, Murray Hill, New Jersey. The varactor, developed under Signal Corps sponsorship, is useful for low noise microwave amplification, modulation, switch wave amplification, modulation, switching, electronically variable attenuation and harmonic generation.

Dr. Uhlir received B.S. and M.S. degrees in Chemical Engineering from Illinois Institute of Technology and the S.M. and Ph.D. degrees in Physics from the University of Chicago, where he was an AEC predoctoral fellow from 1949 to 1951. Since 1951 he has been in the Transistor Development Department of the Bell Telephone Laboratories.

Dr. Uhlir is a member of the American Physical Society, Sigma Xi, Phi Lambda Upsilon, the American Association for the Advancement of Science and the Institute of Radio Engineers.

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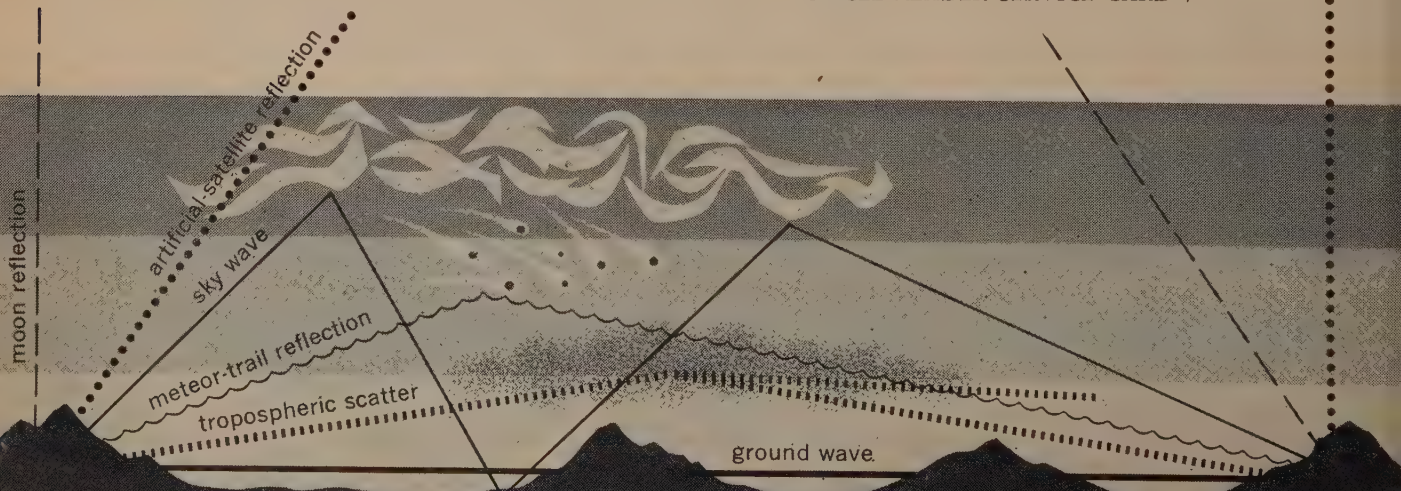
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**EDWARD L. GINZTON** was born in Russia on December 27, 1915, and came to the United States in 1929. He received the B.S. in electrical engineering from the University of California in 1936, and the M.S. in 1937. He received the E.E. degree in 1938 and the Ph.D. degree in 1940 from Stanford University. Dr. Ginzton is now a professor of applied physics and electrical engineering at Stanford, and is the Director of the Microwave Laboratory there. Dr. Ginzton has written many papers in the field of electronics and microwave physics, and has recently had published a text on microwave measurements. He is the sole or joint holder of approximately 50 patents on various microwave devices and circuits. He is a member of Sigma Xi, Tau Beta Pi, Eta Kappa Nu, and in 1951 was made a Fellow of the IRE for his contributions to the development of high-power pulsed klystrons. In 1958 he was the recipient of the Morris Leibmann Award presented by the IRE.

**GEORGE CLARK SOUTHWORTH** was born at Little Cooley, Pa., on August 24, 1890. Dr. Southworth did undergraduate work at Grove City College and graduate work at Columbia and Yale. During World War I he was occupied with research work at the Bureau of Standards and Yale University. He was with the Bell System from 1923 until 1955, when he retired to become a consultant. He is the author of a score or more of scientific papers on diversified radio subjects. His work culminated in 1950 in a 675-page textbook on microwave techniques, "Principles and Applications of Waveguide Transmission."

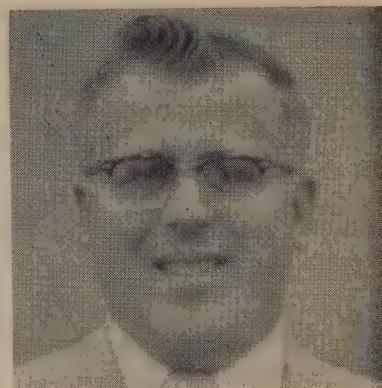
For his work in waveguides, Dr. Southworth received the 1938 Morris Liebmann Prize of the IRE, and in 1947 the Stuart Ballantine Medal of the Franklin Institute. He is a fellow of the IRE, the American Physical Society, and the American Association for the Advancement of Science.



**PAUL A. CRANDELL** (A '52-M '57) graduated from Boston College in 1951 with the degree Bachelor of Science in Physics. He then joined Raytheon Mfg. Co. where he spent almost 2 years in the Power Tube Division as a microwave engineer. In 1952 he joined the Laboratory for Electronics in Boston, Massachusetts, where he worked on microwave and radar systems. He worked for Sylvania, Missile System Laboratory as a section head in charge of transmission line and antenna problems from 1956 to 1958. In June of 1958 he received his M.S. in Physics from Boston College and then joined National Company, Inc. as a staff engineer.

**FREDERICK J. DOMINICK** was born in Salem, Massachusetts on March 30, 1930. He was graduated from Boston College with the degree of Bachelor of Science in physics in 1953. He is at present attending Northeastern University and will receive his degree of Master of Science in physics in January 1959.

Mr. Dominick was employed from 1953 to 1955 by the American Machine and Foundry Electronic Division as a junior engineer. From 1955 to 1956 he was employed by Bomac Laboratories as an engineer where he was primarily associated with gas switching devices. In November 1956 he joined the Missile Systems Division of Sylvania Electric Products Inc. in Waltham, Massachusetts. He was supervisor of all RF devices that were associated with project Plato. At present he is associated with Ewen Knight in Needham, Massachusetts where he is currently working on paramagnetic and parametric amplifiers and other solid state electronic devices.



**GERSHON J. WHEELER** has been in the field of Microwaves since 1942. At present he is an Engineering Specialist at Sylvania's Microwave Physics Laboratory, in charge of ferrite device development and consulting on special microwave problems. Before this, he was a microwave consultant at Raytheon Manufacturing Company, where he was employed from 1950 to 1957. He is a senior member of the IRE and a member of RESA.

## *Guest Contributors*

# MICROWAVES

## PART 1

By E. L. GINZTON

DIRECTOR, MICROWAVE LABORATORY

W. W. HANSEN LABORATORIES OF PHYSICS

STANFORD UNIVERSITY, STANFORD, CALIFORNIA

Although the term *microwave* is often encountered in the technical and scientific literature, it may be well to begin this review by restating the meaning of this term as it is known to the workers in the field. It is convenient to think of the electromagnetic spectrum as being divided into two parts which differ from each other in the methods available for the generation and detection of radiation. The first of these regions, that of shorter wavelength, is characterized by the fact that both generation and detection of radiation involve quantum effects (such as the radiation of light from an atom arising from the transition of electrons from one energy state to another). In this region can be listed cosmic radiation, visible light, infrared, and so on. The second part of the electromagnetic region, called the radio region, is characterized by the fact that electromagnetic energy can be generated by the circulation of electrical currents through conductors and, in contrast to the first case, the frequency of radiation can be controlled by selecting the size and configuration of electrical circuit elements. It is the extreme high-frequency end of the radio spectrum which is called the "microwave region," and these radio waves are called, for brevity, "microwaves." This qualitative definition of microwaves indicates that a clear distinction cannot be made between microwaves and short radio waves on the one hand, and microwaves and infrared radiation on the other.

At the present time, for various reasons which will be considered, it has not been possible in any practical way to generate radiation having a wavelength shorter than a few millimeters. The long-wave end of the microwave region is also vague, and microwave devices and techniques are occasionally used at frequencies which are attainable by refinement of ordinary radio devices and practice. Thus

microwave principles and techniques are sometimes found useful at wavelengths as long as 100 centimeters. Expressed in units of frequency, the microwave region can be said to extend from about 300 megacycles to about 150,000 or 200,000 megacycles. This is a very large frequency domain, which provides room for many classes of radio service which find themselves crowded in the ordinary radio region which, by comparison, covers only a few hundred megacycles.

In considering the objectives of research in this field, it is important to observe that, in contrast to many branches of science, there is no intrinsic interest in conducting research in this field in itself. Whereas, for example, one can study cosmic particles in the hope that this study will shed new light on the basic properties and laws of nature, the study of microwaves in the same sense is pointless. The study of electromagnetic phenomena in the visible and radio regions during the last century has firmly established fundamental principles, and these, of course, govern the behavior of microwaves as well, even though the generation and observation of microwave phenomena did not become really practical until quite recently.

This does not imply, of course, that research which makes use of microwave techniques is not possible or profitable—quite to the contrary. The availability of electromagnetic radiation in the microwave region has opened up broad new areas of research in many fields. The significance of microwave research can perhaps be best understood by briefly describing some of the major fields of activity made possible by the development of methods of generation, detection, and measurement of microwave radiation. This will be attempted in the section on "Current applications" below.

It is important, then, to observe that research in the microwave field is clearly governed by the possible applications to which a particular discovery or development might lead. In other words, research in the microwave field must, of necessity, be *applied research*, always directed toward a useful goal in some other field. The fact that microwave research is of applied nature does not mean that the work is either mundane or of limited interest. Both the nature and methods of research are often most challenging, and it is gratifying that the results of the work frequently find application as both tools of fundamental research and in more conspicuous practical applications. Examples of the former are the use of microwaves in spectroscopy, in radio astronomy, and in particle accelerators; and of the latter, their use in radar, television relays, communications, navigation, cancer therapy, food sterilization, and home cooking ranges.

Since microwaves are radio waves, it is not surprising that the problems encountered in the field are those well-known in radio technology. These are: methods of generation and amplification of radiation; reception, detection, and amplification of incoming signals; and methods of measurement of the electrical quantities which are needed to describe accurately the behavior of electromagnetic waves in an experiment or system. Just as often happens in the ordinary radio region, many of the new microwave problems arise because it becomes of interest or importance to try to work at frequencies which have not been successfully used before, or to generate a greater amount of power than has been heretofore possible; or to try to find methods of amplification which would permit the detection of weaker signals, more closely approaching the theoretical limits imposed upon a given system by its temperature. All of these are practical problems, but their solution may permit, for example, a better understanding of molecular structure, or a novel astronomical observation.

In addition to describing the various applications of microwaves for the purpose of general interest, this article will be concerned with discussion of some of the problems that are encountered in finding means to generate, detect, and amplify power in a manner dictated by those appli-

cations which are now known to the workers in the microwave field. A more complete discussion of the principal areas of application of microwaves would be beyond the scope of this article.

## Origin

There are four general reasons for the original and continuing interest in the microwave region. First, the development of successful methods of generation and detection of microwaves has made possible the investigation of certain classes of physical and chemical phenomena; microwave molecular spectroscopy is an example of one technique which is used in this work. Second, the wavelength of microwaves is so short that it is quite practical to build transmitting and receiving antennas which are large compared with the wavelength; thus, many principles of physical optics can be made to apply, and as a consequence it is possible to focus and direct microwave radiation in a manner similar to that of light. Third, the wavelength of microwaves is still sufficiently long so that these waves, like ordinary radio waves, are not scattered and stopped by rain, fog, or clouds. Fourth, as mentioned before, the region between the shortest and the longest end of the microwave region is extremely wide in terms of frequency. Until the advent of microwave devices, all types of radio service had to be contained within a region of a few hundred megacycles. Consequently, the development of radar systems and of equipment for aircraft navigational and blind-landing aids and the expansion of communications of all types became feasible only after the microwave region of the spectrum became usable. The microwave region extended the frequency range available by a factor of approximately a thousand and will probably provide sufficient room for most of the foreseeable demands for many years.

It is difficult to present an accurate historical account of research in the microwave field because it developed slowly at first and extremely rapidly in the recent past. It is of interest to note that the first experimental verification of Maxwell's theories was carried out by Heinrich Hertz in 1888, and that this work was in the microwave region. In a series of now-famous experiments, Hertz demon-

strated the feasibility of radio propagation and the identity of Maxwellian radiation and ordinary light by showing that, like light, "microwaves" obeyed the known optical laws of reflection, refraction, and polarization. These experiments were repeated by others, and, after a rapid improvement in technology, the first radio communication was established. In the course of the original development the primary interest centered on the problem of communication over long distances and, hence, the need for comparatively high power. This could then be obtained only at longer wavelengths, and the original "microwaves" were all but forgotten. Serious interest in the possible use of very-short-wavelength radiation did not begin until the mid-1930's, when it became increasingly evident that methods of rapid, precise detection of aircraft through fog, clouds, and darkness would be of great military value.

## Development

From the time of the early workers in the field—Hertz, Lodge, Muirhead, Popoff, Braun, Tesla, Marconi, and others—to the beginning of the intense development work in the late 1930's, many significant contributions had been made by scientists throughout the world. The experiments of Hull with the split-anode magnetron in the early 1920's and the further development of this device by workers in Japan, made it possible to generate small but significant amounts of microwave power. In the early 1930's, work began on molecular spectroscopy, and this and related research led to further improvement in methods of generation, detection, and measurement.

Theoretical studies in the 1930's were also of major importance. Southworth and his collaborators at the Bell Telephone Laboratories, and Barrow at Massachusetts Institute of Technology, discovered the principles of guided propagation which eventually led to the wide-spread use of hollow pipes as a means of conducting electromagnetic energy from one place to another, instead of the wires which had been used before. The development of these transmission-line concepts was fundamental, since they made possible a system for transmission of high-frequency power without appreciable loss (which would otherwise be expected), and also be-

cause they provided an understanding of the behavior of electromagnetic waves in bounded regions. Another important contribution during this period was due to Hansen at Stanford University, who showed that empty or dielectric-filled containers could act as resonator circuits, just as the coil and condenser do at the lower radio frequencies.

In the middle 1930's the generation of microwave power in the amounts required for practical applications was difficult for two principal reasons. In all power-generating devices which use electrons it was considered necessary that the flight-time of the electrons across a given electron tube be small compared with the period of a single cycle of the radio-frequency wave. This was thought to be a fundamental limitation on the generation of high-frequency power since, if the time of flight were a full cycle, any work done by the electrons on the circuit during the first half-cycle would be cancelled by the work done by the circuit on the electrons during the second half-cycle. Electron tubes were designed, then, so that the flight time was negligible compared with a cycle, and this in turn meant that it was necessary to make the tubes smaller and smaller as the intended frequency increased. Because of this limitation, and the necessity of using low-efficiency coil-and-condenser circuits, it appeared that it would be impossible to generate any substantial amount of power at microwave frequencies—not enough, in any case, to be useful for most practical applications.

The fundamental "transit-time" limitation mentioned above was eventually circumvented by a new method of obtaining radio-frequency power in electron tubes. The new development was the result of the discovery of the so-called "velocity modulation" of electron streams, which was due to Heil and Heil in Germany, the Varian brothers at Stanford University, and Hand and Metcalf at General Electric. Instead of attempting to make the electron flight-time inside the vacuum tube small, the principle of velocity modulation made intentional use of transit times which were very large. To convert a homogeneous electron stream into a pulsating one which could deliver power to a high-frequency circuit, the electrons were made to *bunch* along their path

because of the difference in their speeds.

The combination of the principle of velocity modulation of electron beams and the "cavity" resonators of Hansen led to the important development, in 1937-39, of the "klystron" tube, which proved capable of performing, at microwave frequencies, many of the tasks expected of the conventional vacuum tube at lower radio frequencies.

The beginning of World War II accelerated the development of the microwave field by demanding greater power, better detection systems, and a more complete understanding of the various problems associated with the use of microwave methods for radar and communication. Important discoveries in England led to rapid development of the magnetron and eventually permitted this device to deliver a peak power of several million watts at wavelengths in the neighborhood of 10 centimeters.

It is not appropriate to attempt a complete description of the many significant accomplishments in microwave technology during the war. However, it may be of interest to note that the work of the Radiation Laboratory of Massachusetts Institute of Technology eventually led to the publication of a 20-volume series which dealt with the theory and application of microwaves to the radar problem. Because of the importance of the problem, the state of the microwave art advanced a remarkable distance in a short period of five years. Not only were many complicated and successful systems developed, but theoretical understanding of almost all aspects of the field also reached a point of near perfection. The practical devices which emerged from this work were far advanced in nearly every major respect. For example, more peak power could now be obtained at microwave frequencies than had been obtained at the lower radio frequencies; radio receivers could distinguish signals which were only ten times as large as the noise due to natural causes (thermal agitation) in the circuits themselves; theory and design of antennas were highly developed; measurement techniques were perfected to the point where all of the usual electrical quantities could be measured nearly as well as they could be in the radio region, which had been under study for the preceding 50 years; the theory of the behavior of electromagnetic

waves in closed regions was highly developed, and the transmission theory could be considered virtually a closed topic except for details of design.

As a result of these war-time developments, it was clearly evident that the future of the microwave field held great promise. Many of the expectations of this period have been fulfilled in post-war developments. Some of the more important of these are described below.

### Current Applications

*Communications and defense.* Perhaps one of the simplest and most direct consequences of the war-time developments is the use of radar for maritime purposes. Today every large ship carries one or more radar sets for the purpose of navigation in bad weather. Although present maritime rules prohibit navigation solely by radar, its use contributes in large measure to the prevention of serious maritime accidents. Maritime radars are designed to indicate the presence of ships, land masses, icebergs, and other objects at distances as far as the horizon. Other types of radar are designed to locate accurately objects close by, and this information is useful in navigation through narrow channels, in harbors, rivers, and in the Great Lakes.

Radar is equally useful in the navigation of aircraft. Although an ideal navigational system has not yet been developed, radars of several types are in constant operation at every major commercial airport; these are used to establish safe traffic patterns by stacking and controlling the aircraft and are also used to assist in landing the aircraft in bad weather. Some modern aircraft also carry airborne radar which permits them to detect adverse weather conditions which are not suitable for convenient or safe flight.

One of the principal present uses of microwaves is in providing a means of communication where a broad frequency bandwidth, on the order of several megacycles, is required. This bandwidth is necessary for rapid transmission of signals which contain a large amount of information, television being an important example. In the United States today, every major city can now receive television programs which originate anywhere else in the United States. This is accomplished

by transmitting microwave power over short distances, say 20 miles, and repeating the transmission to cover longer distances. Many countries in Europe and elsewhere have similar networks of "repeater" transmitters either in operation or in development. Some of these countries are also developing similar relay networks to augment or replace the older wire systems of telephone communication. In many parts of the world, microwave methods provide the only practical form of communication. In addition, the recently developed form of microwave relay communication which uses the method of scatter-reflection from the atmosphere makes possible relatively long-distance communication; and this provides means of communication in those sections of the world where closely spaced relay links are either impractical or unnecessary.

The applications of microwaves in defense systems are both numerous and important. Microwave applications are found in nearly every branch of the military service and are used for radar, communication, and navigation, and for the launching, guidance, and fusing of missiles. Some of the defense projects which use microwave techniques have reached very large proportions as, for example, the DEW radar line being built jointly by Canada and the United States.

*Science and industry.* Just as spectroscopy studies of the emission and absorption of visible radiation have led to an understanding of atomic structure, microwave spectroscopy studies have brought about a more complete understanding of molecular structure. A number of potential applications of great importance have come from this work. An example of these is the development of the "atomic clocks." In one of these atomic clocks, use is made of the spectral line associated with the characteristic inversion frequency of an ammonia molecule. This line, located conveniently at 23,870 megacycles, is extremely stable and is therefore useful as a frequency standard. This spectral line can be observed either by finding the center of the absorption band or, alternatively, by the recent discovery of "induced emission" in a device called the "maser," which will be described in greater detail later. By using one of these methods, it is possible to construct a device which will produce microwave signals whose

frequency can be made considerably more stable than the frequency of any other man-made source. By reducing the frequency by conventional electronic methods to the neighborhood of 1000 cycles, it is possible to use this frequency to operate an ordinary clock. The time derived from an atomic clock by such methods promises to provide a new standard of time, which will be independent of the fluctuations which are known to occur in the present standard, the rotational frequency of the earth. If atomic clocks can be made to attain the precision which present experience indicates is possible, many important discoveries and practical developments should result. In the field of science, for example, it should be possible to repeat the famous but inconclusive experiment of Michelson and Morley to more accurately ascertain whether ether drift does not, in fact, exist. Another application is the possibility of devising completely laboratory-contained experiments to test the theory of relativity.

One of the possible practical applications of extremely stable frequency sources is that of devising new types of navigational systems for use in the air and at sea, and possibly—should the need arise—in the space beyond the earth. If a radio transmitter and receiver, with oscillators operating at precisely the same frequency, are located, respectively, at a fixed station and on a moving vehicle, then the motion of the vehicle will result in the received signal being Doppler-shifted. By comparing the received signal with one generated in the vehicle, the velocity of the vehicle can be determined simply by measuring the frequency difference; and the vehicle's position can be found by integration of the Doppler frequency—that is, by counting the cycles of the frequency difference during the time elapsed. Stability of an oscillator on the order of one part in  $10^{10}$  should result in the determination of vehicle velocity to an accuracy of 1/20 mile an hour. Such stability in atomic clocks does not seem impossible, and is in fact already being approached by some of the devices now being tested.

The ammonia maser can also be used as an amplifier of weak signals. Since it does not use charged electric particles in the process of amplification, the usual noise-generating mechanism in receiver circuits is not present, and this, in principle, makes

it feasible to build "perfect receivers"—that is, receivers which can identify electrical signals which are just slightly larger than the natural noise existing in space. This goal has been the object of extensive research at all radio frequencies, including the microwave region; however, at microwave frequencies the known methods of detection and amplification have always resulted in the introduction of noise by the detector or the amplifier to the extent that it has been impossible to detect signals which were weaker than approximately ten times that of the natural noise. It has already been demonstrated that the ammonia maser can bring about a significant improvement in the quality of microwave receivers, and these discoveries have stimulated research along related lines.

Another application of microwave power is its use in accelerating particles to very high energies. High-energy electrons, for example, are useful for many purposes: in the range of a few million volts, they may be used for sterilization of food, drugs, and other products and for inducing chemical reactions not otherwise easily produced; in the energy region from a few to 20 or 30 million volts, they are useful for generation of x-rays for industrial radiography and for cancer therapy; in the energy region above this, extending into the multi-billion-volt range, electrons are useful as an important tool of nuclear research. In each one of these applications, microwave methods of accelerating particles are convenient and practical, and in some cases represent the only known method of attaining the desired result. The state of contemporary microwave practice is sufficiently advanced in these fields so that no fundamentally new research is required. What is necessary, of course, is the investment of large sums of money for development and construction of appropriate machines.

Still other applications of microwave radiation may be mentioned. Radio-frequency heating has been a standard technique available to industry, and it is not surprising that microwave power should also find application for this purpose as well. Generally speaking, the methods of generating microwave power are not as efficient as those used to generate the lower radio frequencies. Therefore, microwaves are used for heat-

ing purposes only when there is some specific advantage to be gained at shorter wavelengths. A few of the applications in which this is the case are the following. Molding of certain plastic materials can be conveniently carried out by introducing microwave power into the molding-machine cylinders just prior to extrusion. Also, powdered plastic material which is contained in a metallic cylinder can be made to be a resonant microwave circuit and will therefore absorb microwave power readily and rapidly. This process lends itself to mass production of plastic products. A third application, based on the same principle, is the microwave kitchen range. In this application, many kinds of food, by virtue of their dielectric properties, can be heated almost instantaneously.

### Current Problems

As has been noted above, microwave research is oriented toward applications in other fields of science and toward industrial applications, and it has led to many important advances. We now turn our attention to some of the central problems which presently concern workers in the field, and also consider further possible applications which might arise. It should be noted here that the following observations do not include activities which are basically a refinement or an extension of known principles, although such work is, of course, very important; it would not be possible to provide a comprehensive description of even the most significant of these activities. The problems considered below are arbitrarily confined to those which involve the search for new principles, new methods, and new applications.

The following general areas of the microwave field are now receiving or can usefully receive attention as topics of research. The general topics listed, and some current approaches to these, are described below in greater detail.

*Extension to higher frequencies.* In the mid-1930's it was important to find practical means of generating microwave power; one of the central problems at the present time is to find methods of generating radiation in the frequency region beyond that now usable—in the millimeter and submillimeter range. As with the earlier work, there are specific and general reasons for this interest.

Among the specific reasons are those which concern the use of short wavelengths in the field of molecular spectroscopy, and also the further extension of the usable frequency spectrum for the continuously growing needs of the communication industry. The general reason, which is the one that fundamentally motivates all new microwave research, is that no one can now predict (just as no one could have predicted the multifarious applications of radio and microwaves) what future applications and discoveries the availability of this broad new spectrum will lead to. It is of very great interest to find methods of generating radio-frequency power in the region between radio waves, on the one hand, and infrared radiation on the other. An immediate objective of research in this field is to find new methods which will increase the available spectrum by another factor of ten, reaching perhaps down to a wavelength of 0.1 millimeter.

These objectives cannot be reached by simple extension of present electronic methods of generating radio-frequency signals. All presently known electronic devices have a fundamental high-frequency limit above which they cannot be made to work. The details of these limitations are complicated, but some insight into the main reasons can be quite readily attained. As the wavelength at which one is interested in building a microwave generator is made shorter, the physical size of the device is necessarily made smaller in proportion. All microwave devices require the use of cavities or circuits whose dimensions are related to the operating wavelength. It also happens that in all electronic devices there is a critical amount of electronic current which must be made available in order to permit operation. If the available current is less than this critical amount, operation of the device becomes impossible, because the power that can be generated by this current is not sufficient to supply the heating losses in the circuits of the device. But as the wavelength of the device is made smaller, the region through which the electron current must pass is also made smaller. This means that the higher the frequency, the lower is the available current, and this is further complicated by the fact that, in general, the required current becomes higher. This situation can be made clearer by considering a specific situation—for example, a

klystron, the simplest of all microwave devices. Figure 1 is a schematic diagram of a klystron, in which an electron beam is produced by accelerating electrons from a cathode and focusing them into a cylindrical beam. Along this beam there are a number of resonant cavities, the first of which permits variation of the electron velocity, due to the radio-frequency voltage across its opposite poles. Subsequently, because of the velocity variation, the electrons group themselves in bunches and are able to impart their kinetic energy to the potential energy of the last resonator. The exact process of generation of microwave power is not important for this discussion, but it is important to note three things: (i) as the wavelength is made shorter, all of the dimensions in Fig. 1 need to be reduced in proportion to the wavelength; (ii) as a result, the amount of current available from the cathode is reduced in proportion to the area of the cathode—that is, is reduced as the square of the wavelength; (iii) the losses in the conductors of the resonant cavities become higher. Thus, as the wavelength is made shorter, the available current is smaller, although the required current is greater. At some specific wavelength, therefore, a device of this sort will cease to work. A more careful analysis of this problem demonstrates that a klystron cannot be made to work at wavelengths

appreciably shorter than a few millimeters. For other types of microwave generators, such as the magnetron and the traveling-wave tube, the differences in the final result are surprisingly small, in spite of the substantial difference in the method of operation and the configuration of the various devices.

As a result, it has been clear for some time that higher frequencies cannot be attained by application of presently known electronic principles. Several systematic searches for other possibilities have not yet revealed any plausible approach to the problem. The workers in the field have therefore a new challenge: to find a solution to a seemingly hopeless problem. The situation today in this field is similar to that in the mid-1930's, when methods of microwave generation were unknown. The present picture is not completely pessimistic; some suggestions are being explored along lines which will be described in a later part of this article.

*Generation of higher power.* For several possible applications it would be desirable to provide even greater power than has been attainable before. Either higher peak power, or higher average power, or both, are of interest. The question of increasing the average power is important, for example, in applications involving industrial heating, television and radio transmitters, and so on. In other appli-

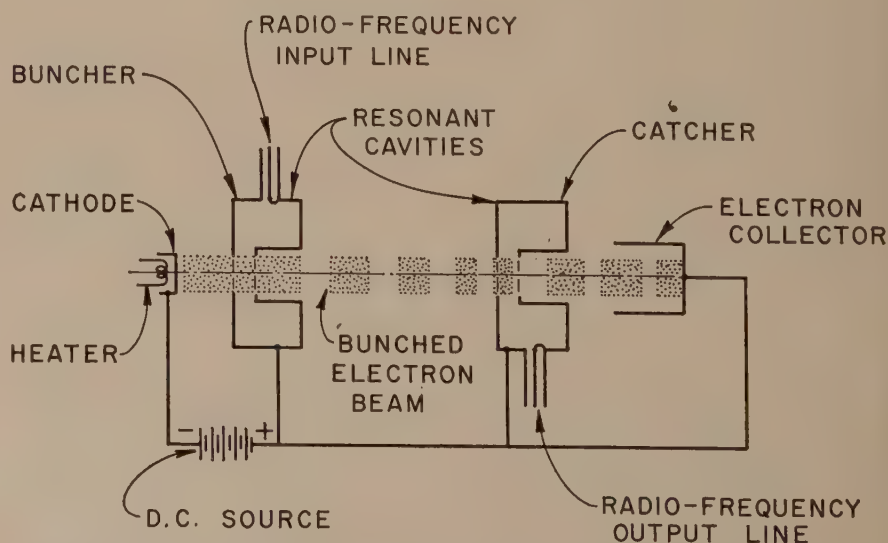


Figure 1—Essentials of a klystron tube. Electrons emitted from a cathode are accelerated and focused into an "electron beam." The electrons, in passing through the "buncher" cavity, experience time-varying forces due to the radio-frequency fields there. The resultant motion of electrons creates bunches of electrons, approximately as shown. These create pulsating forces in the "catcher" resonator and thus induce amplified signals which can be removed by a coupled transmission line.

cations, such as radar and particle accelerators, it is often of interest to be able to generate higher peak power.

In addition to the question of the power level, another requirement of primary importance in many transmitting systems is the ability of the transmitter to respond to large frequency bandwidth—that is, the range of frequencies which a transmitter is capable of amplifying simultaneously. Questions of this type are especially important in radar applications, and the search for methods of amplifying large bandwidths at high power levels represents one of the most important problems in this field.

*Detection and amplification of weak signals.* Detection and amplification of weak signals is clearly as important as generation and transmission of higher power. At the present time the principal effort to improve the ability of microwave receivers to respond to weak signals has been devoted to studies of traveling-wave tubes, although the results of this

work are applicable to other microwave devices as well. However, because the traveling-wave tube, in common with all electronic devices, uses charged particles, the noise generated in the tube by the electron stream is not negligible, despite efforts to minimize such noise. When the present performance in this field is compared with radio standards, traveling-wave tube operation seems nearly as good as one can expect. But the recent invention of the maser has shown that amplification can be obtained without the use of charged particles. This has led to new possibilities for reduction of noise in detecting and amplifying systems, and these will, without question, be of great importance in the future.

*Other applications.* The general areas of interest for further research have been stated in terms of microwave applications which are either known today or are possible if certain specific microwave objectives can be attained. It is probable, of course, that still other applications of micro-

waves will be found. There is much to be gained from new ideas, new applications, and new methods will continue to be as important as it has been in the past.

There are two areas which seem to provide exceptionally great opportunities for research at the present time. One of these concerns the extension of principles introduced by the invention of the maser: the applications arising from microwave signals which are obtained from systems that do not use electron beams. The second area of speculative interest is the study of possible applications of plasma phenomena in microwave systems—that is, gaseous media in which all or nearly all atoms are ionized. Nearly all radio-frequency generating devices employ electrons exclusively; in retrospect, this seems like an artificial restriction upon the potentialities of electronic devices. That plasma applications have received only limited attention, to date, is due to the fact that plasma phenomena are extremely complicated. The possible importance of this subject, however, is great.

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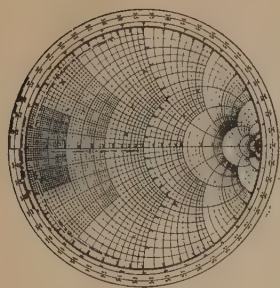
In the opinion of the Editors of "the microwave journal," the excellent context of this paper was considered admirably suited to our specialized readership.

Part II will appear in our next issue.

# More About Phil Smith . . .

## . . . and his diagram

George C. Southworth



In a recent issue of this Journal some good words were said about Phillip H. Smith and the diagram for which he is so justly famous. This writer is always glad to see an honor accorded to a friend and colleague but he feels that very much more could and should have been said. Thus the remarks that follow. In this writer's opinion, the Smith diagram has been one of the more important device contributions made to microwave technique during the last couple of decades. True enough, similar results could have been produced by suitable calculation, but this device brought with it not only quantitative calculations but a good measure of enlightenment concerning the job it was doing. This writer has a strong preference for things that teach.

Though a mere sheet of paper with a peculiar grid of intersecting circles together with provision for constructing other significant circles all with appropriate radius scales, this magic device does a variety of useful tricks. In general, it makes it possible to solve very simply, and with an accuracy sufficient for most purposes, a number of rather involved equations. Some involve hyperbolic functions, a subject to which many engineers are highly allergic. By the usual analytic processes, the steps at best would ordinarily be very laborious. Even more important, the Smith diagram makes it possible to visualize while the work is in progress the step-by-step processes that are under way.

Indeed, it is the "feel" for the problem that has the strongest appeal to most engineers. It is somewhat as though a student, who had worked only with ordinary algebraic equations, should suddenly learn how to plot these equations on ordinary co-ordinate paper. For him, the new experience would be very revealing indeed.

To appreciate better the part that the Smith diagram has played in communications, it is desirable to review certain steps in the evolution of communication theory. Long before the advent of the Smith diagram, transmission line theory had clearly shown that a source of alternating current placed at one end of a long uniform transmission line could give rise to waves of current (or voltage) traveling from the source toward a load located at its remote end. As might be expected the wave was propagated with a *characteristic velocity* and in turn gave rise to a wavelength which depended not only on the frequency but on the properties of the line itself. Also the wave was attenuated as it progressed along the line. In this case, the *constant of attenuation*, as it was called, depended among other things on the resistance of the wires constituting the line and the electrical leakage between them. Still another important property of the line, known as its *characteristic impedance*, depended on the geometrical shape of the two conductors and their relative spacing. This particular constant was of such great funda-

mental importance that it subsequently became a common denominator against which other constants of the line could be compared. More particularly the impedance of the load and the impedance of the input generator were often divided by the characteristic impedance to provide so-called *normalized impedances*. This greatly simplified the mathematical work in progress. It subsequently proved to be almost an essential to the success of the Smith diagram.

As the theory of transmission lines unfolded, it became evident that the appearance of the load as viewed from the input end of a low-loss line was not a constant, but varied with the length of the line. This result which at first may have appeared somewhat surprising proved to be an extremely useful property. For, this meant that by a proper choice of line length, a capacitive load, for example, could be made to appear from the input end as though it were any one of a number of predetermined impedances. It could, for example, be made to appear as a capacitance of the same or another magnitude; it could be made to appear as a pure inductance of either of two magnitudes; it could be made to appear as a pure resistance of either of two magnitudes; or, it could be made to appear as any of a wide range of combinations of impedance components. Thus a transmission line had a transformer property. This was destined to play a very important part in modern microwave technique.

It is particularly significant that while those skilled in the mathematics of transmission lines might, at an early date, have freely interpreted, from the equations, the significance of these transformations and accordingly might have calculated the result accurately in advance, it is doubtful, if this was actually done by any great number of people. However, with the advent of the Smith diagram, not only were the mathematical steps carried out but thousands of engineers were enabled to understand more clearly what was being accomplished. If, in a given setup, a correct transformation was not satisfactorily accomplished, it became possible from the diagram to determine why the transformation failed. The Smith diagram has, through the years, assisted materially in numerous inventions.

If the calculation and interpretation of the transformer action had been the only accomplishment of the Smith chart, it alone would have seemed quite rewarding but there was much more in store. As already indicated, transmission line theory had clearly shown that waves could be propagated from the source toward the load. As might be expected, from similar examples of physics, these electric waves upon arrival at the load were in general partly absorbed and partly reflected. Also, as expected from other similar problems, the presence on the line of oppositely directed (reflected) waves of the same frequency should give rise to wave interference and accordingly to the phenomenon known as standing waves. These would be attended by characteristic nodes and loops. Around the phenomenon of standing waves there developed a second very useful field of application for the Smith diagram and this will be discussed next.

Electrical theory had already accounted for the reflection of wave-power by a load placed at the end of a line. It had shown that all pure capacitances and also all pure inductances were perfect reflectors. It had also shown that pure resistances were good reflectors provided they were either very large or very small. At intermediate values of resistance, perhaps in the vicinity of characteristic impedance of the line, the reflection could be very small indeed. In fact at a particular value known as characteristic resistance there should be complete absorption. Elimination of

reflections was one of the objectives aimed at during the early days of radio-frequency transmission lines.

It is of very great importance to note that under conditions of nearly perfect reflection, particularly with low-loss lines, very pronounced standing-wave minima may be produced. In fact the depth of these minima becomes the basis of one of the favored methods for measuring small losses. It is of interest also that the voltage minima produced by the three types of loads noted, differ significantly with regard to their locations relative to the end of the line. More particularly, those due to pure capacitances are located somewhat less than a quarter-wave from the end of the line, those due to pure inductances are located somewhat more than a quarter-wave from the end of the line while those due to pure resistances may be either at the electrical end of the line or a quarter-wave removed depending on the magnitude relative to characteristic resistance. For loss-less transmission lines such as may be approximated in waveguide practice, it is possible to determine from depth of minima as well as their position along a transmission line, the more important facts about the nature of the load. Thus the nearly loss-less transmission line affords a method of measuring impedances. As before, the calculations attending these measurements are rather involved and as before a special feature of the Smith diagram makes it possible to scale off these quantities. In this case, the reflection coefficient is taken from a scale placed along the radius of the circular chart. The nature of the reflector is identified more closely with a quantity known as the angle of the reflection coefficient. The latter is read from a scale located around the periphery of the diagram. As might be suspected, the transformer action referred to above is not altogether unrelated to the standing wave phenomena discussed later.

It should be noted in passing that incidental to the study of standing waves, a quantity known as standing wave ratio is of very great importance. As its name implies, it is a ratio of maximum to minimum in a standing wave. It may be specified either in terms of relative powers, relative currents or relative voltages. On the Smith diagram, the phase between incident and reflected voltages

may be read from an appropriate peripheral scale.

Much of the discussion above has centered around transmission lines free from loss. Often the engineer wishes to know about the attenuation taking place in the line in which he is working. In fact attenuation has been one of the time-honored problems of communications. In the Smith diagram, line attenuation is read from a scale placed along the radius of the circular diagram but it is of course a different scale than either that used in measuring reflection coefficient or that of standing wave ratio.

Tallying up the score for the accomplishments for the Smith diagram, we have the rather impressive array that follows:

- I. A convenient grid on which we may plot impedances showing not only positive and negative reactances but resistances. A feature of this device is that diametrically opposite points on the diagram provide corresponding values of admittance complete with appropriate values of positive and negative susceptance as well as conductance.

- II. The grid is of a special kind such that by mere rotation, a point representing a given load impedance is carried to another point on the grid specifying the impedance as it would appear at the corresponding angular distance along any loss-less transmission line.

- III. The magnitude of the reflection coefficient of a given load plotted on the grid may be easily read from an appropriate radial scale.

- IV. The angle of the reflection coefficient also may be easily read from a peripheral scale.

- V. Standing wave ratio, as specified by any of three well-known bases, may be read on a radial scale.

- VI. The very important attenuation constant incidental to losses in a transmission line may be readily determined.

- VII. Certain other quantities that may be scaled include reflection loss and standing wave loss coefficient. To this may be added numerous variations and special applications not originally conceived by Mr. Smith. In one very ingenious variation accredited to Messrs. F. F. Rieke and J. E. Evans, and applicable particularly to microwave oscillators, data concerning relative frequency, relative power and standing wave ratio

as observed on a waveguide transmission line connected to the oscillator, are all plotted on a Smith grid. His results in patterns that reveal much about the internal workings of the oscillator. It is almost as though the experimenter had been permitted to reach inside his evacuated device to make adjustments that hardly could have been feasible.

Possibly inspired by the success of Mr. Smith's diagram, there have followed a multitude of other charts each applicable to certain aspects of microwave theory but most of them seem to be outside of the neat package tied up by Mr. Smith and will not be discussed at this time.

It is perhaps of interest to consider a little of the history of transmission diagrams. It is expected that a more complete history will appear in the words of the originator himself at a later date. A very abbreviated version, pieced together from conversations with Mr. Smith and certain of his colleagues of perhaps twenty-five years ago, follows.

It is the writer's impression that the transmission diagram, even in its earliest form, was no flash of genius. Like for the most of us, Mr. Smith's first ideas were imperfect and they required time for full maturity. It is, however, to his everlasting credit that he did not allow his idea to die on the vine but nourished it until he had brought it to a high degree of perfection. Apparently the most important years of evolution came between 1931 and about 1937. Minor improvements were made as recently as 1950. It all began while he was working with two-wire feed lines to directive arrays such as used in transoceanic radio. At this time, he felt an urgent need to show in simple graphical form the relationship between the components of a terminal impedance and any standing waves that might be present. To meet this need he evolved a diagram still widely used by many in which impedance components including both positive and negative reactance and resistance were plotted in ordinary rectangular coordinates. Two families of curves resulted corresponding to standing wave ratio and distance to the first minimum. This type of diagram continued through the early thirties. In 1935 he was transferred to another group located about fifty miles away. His new colleagues had quite different interests. Thereafter it was necessary

for him to supply his own encouragement. Though the first Smith diagram had definite limitations, particularly with regard to the amount of data that could be accommodated, it proved at an early date to be very useful. There came the time when Smith realized the limitations of the rectangular coordinate diagram and constructed about 1936 a new type of diagram obviating certain difficulties. It was a special polar coordinate form in which all values of impedance components could be accommodated. The impedance coordinates in this case were not orthogonal and were not true circles, but, in the form chosen, the standing wave ratio scale was linear, and the chart closely resembled present day forms. All data from zero to infinity could be accommodated. The data for this diagram were scaled from the earliest rectangular diagram. Though an improvement, Smith suspected that a grid made up of a system of orthogonal circles might be evolved and that this would have distinct advantages, particularly as regards reproducibility.

Acting on this suggestion, late in 1936, he sought the help of Messrs. E. B. Ferrell and J. W. McRae, located in the group from which he had previously been transferred. Being familiar with the principles of conformal mapping, these people were able to develop the transformation to a grid using orthogonal circles and all data from zero to infinity could be accommodated. By good fortune curves of constant standing wave ratio, constant attenuation and constant reflection coefficient were all circles coaxial with the center of the diagram. The scales for these values were, however, not linear but they were still entirely satisfactory. A diagram designed along these lines was constructed early in 1937. It was essentially the form used at present.

At this point things were going beautifully. It remained only to find a customer. There is plenty of evidence that his colleagues listened patiently while he described to them the details of his diagram but there is no evidence that prior to about 1939 anyone in the Laboratories used his diagram. At one time there was a move in the broadcasting industry toward higher powers, and certain outside engineers being interested in transmission line breakdown problems became interested in the Smith diagram

as a means of throwing light on their problem.

Beginning about 1939, one of Smith's former colleagues, Mr. A. G. Fox, by this time, working some distance away on the new subject of waveguides, recognized the utility of the Smith chart in solving standing wave problems and thereafter application in this small group became rather general. Upon the establishment of the Radiation Laboratory at the Massachusetts Institute of Technology in 1942, the value of the Smith diagram was also recognized and thereafter its use became very general indeed. In Mr. Smith's memory, M.I.T. workers were his first customers.

The history of publication of Smith's chart is hardly more inspiring than its development. Soon after the construction of the first of the modern charts, about 1937, Mr. Smith approached editors with regard to the publication. Again acceptance was slow. A description was finally published in *Electronics* in January 1939, after a delay of about two years.

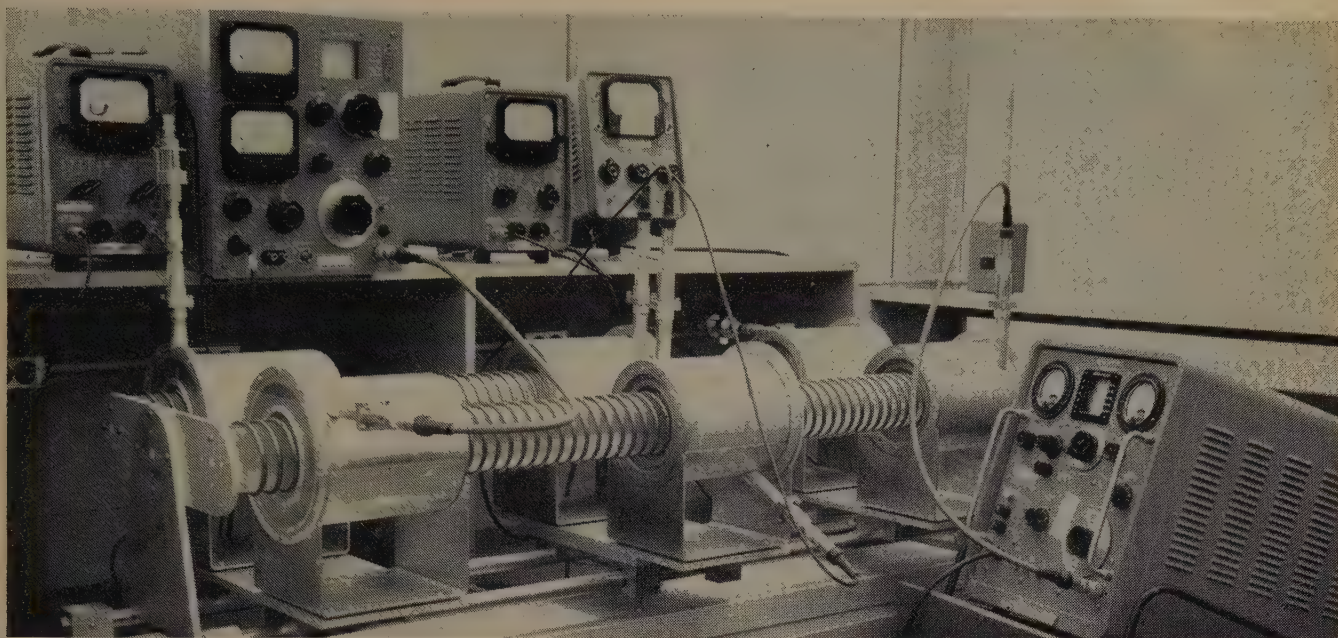
Some idea of the extent to which Smith diagrams are used may be had by the fact that they are now manufactured and sold by at least two companies. They may be had in a number of graph-paper forms including an erasable version. Also, they appear in a plastic form complete with suitable scales. They are on sale at most large university bookstores and they appear as standard stockroom items in large microwave research establishments.

Published papers and memoranda on microwave subjects are often profusely illustrated by such diagrams. Sometimes the completed chart is disappointing in its appearance, particularly for those looking for the spectacular. Often it contains an unimpressively small irregular shaped pattern near its center which the author often exhibits with pride as evidence that his microwave device is practically perfect.

No doubt many other copies of this chart have, through the years, been consigned to the wastebasket. Certain of these discarded copies are probably mute evidence of clever ideas that may have flourished during the wee hours of the morning only to wilt a few hours later when illumined by light shed from a Smith diagram. The Smith diagram is truly a wonderful device!

*This paper describes a device which can be used to change the path length between two terminals with a minimum of mechanical motion. It is essentially an electromechanical device using the principles of coupled helices and spatial beating phenomena. A most effective use can be made of this device in the VHF and UHF fre-*

*quency regions where physically long line lengths become an intolerable mechanical burden. The phase shifter is analyzed according to transmission line theory. Exact dimensions and test results are given for a model which was built using this theory.*



# A HELICAL PHASE SHIFTER FOR V H F

By PAUL A. CRANDELL\*

SYLVANIA ELECTRIC PRODUCTS, INC., WALTHAM, MASS.

FREDERICK J. DOMINICK\*\*

SYLVANIA ELECTRIC PRODUCTS, INC., WALTHAM, MASS.

## I. Introduction

An antenna beam scanner which uses the principle of phasing for beam steering a linear array has been designed. Essentially it is a slow wave helical structure with a coupled non-contacting outer helix. The directionally coupled outer helix can be varied mechanically along the axis of the inner helix to change the line length between two terminals. A series of single coupled helices can be used to program the phase to an array of elements and, in turn, to steer the beam of the array.

## II. Theory of Coupled Helix

As shown in Figure 1, the phase shifting device operates on the principle of coupled helices. The energy incident on  $T_2$  is electromagnetically transferred to the inner helix in the direction of  $T_1$ , thereby producing a non-contacting unity transmission device. With translational motion of the outer helix, this device becomes a phase shifter.

The electric design of the phase shifter was undertaken

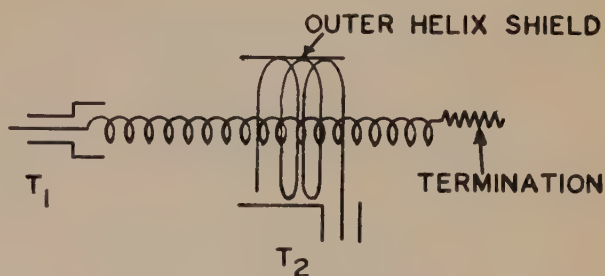


Figure 1 — Diagram of Phase Shifter

according to the theory proposed by Kompfner, et al,<sup>1</sup> which states that if the helices are contrawound and the phase velocities on each helix are equal, complete unidirectional power transfer takes place when the helices are coupled over some appropriate length.

The properties of a concentric helix structure may be investigated by means of field theory; however, interesting properties can be deduced more simply by considering two transmission lines with uniformly distributed self and mu-

\*Paul A. Crandell, formerly with Sylvania, now with National Company, Malden, Mass.

\*\*Frederick J. Dominick, formerly with Sylvania, now with Ewen Knight Corp., Needham, Mass.

tual susceptances and reactances. The use of field theory is inadvisable because of its mathematical complexity. If it were applied, the actual wire helix would have to be replaced by a helically conducting sheet of the same mean radius. Such a conducting sheet, or "sheath helix" as it is usually called, can conduct current only in the wire direction. The reason for replacing the wire helix by a sheath helix is that Maxwell's Equations cannot be solved in an appropriate coordinate system in which the surface of the wire is described by keeping one of the coordinates constant. For a detailed explanation of the solution of Maxwell's equations for a sheath helix, reference is made to a report written by S. Sensiper.<sup>2</sup>

In analyzing a concentric helix structure according to transmission line theory, the concentric helices can readily be compared to two transmission lines of series impedances  $jX_1$  and  $jX_2$ , and shunt admittances  $jB_1$  and  $jB_2$ , coupled by series mutual impedance  $jX_{12}$  and shunt mutual admittance  $jB_{12}$ . Applied to the case in which two transmission lines are coupled together, the transmission equations take the following form:

$$\frac{\partial I}{\partial z} = -jBV_1 - jB_{12}V_2$$

and

$$\frac{\partial V}{\partial z} = -jXI_1 - jX_{12}I_2,$$

where  $jX_{12}$  and  $jB_{12}$  are the series mutual impedance and shunt mutual admittance, respectively. Pierce<sup>3</sup> shows by suitable manipulations that if  $X_1B_1 = X_2B_2$ , there are two modes of transmission: a longitudinal mode in which

$$\frac{V_2}{V_1} = +1,$$

and a transverse mode in which

$$\frac{V_2}{V_1} = -1.$$

When these two modes are excited on the helix, the field distribution is such that the plane where the interfering currents are destructive on one sheath is the plane where they are constructive on the other sheath (see Figure 2). If the currents cancel completely on the inner helix, the condition for complete energy transfer is satisfied.

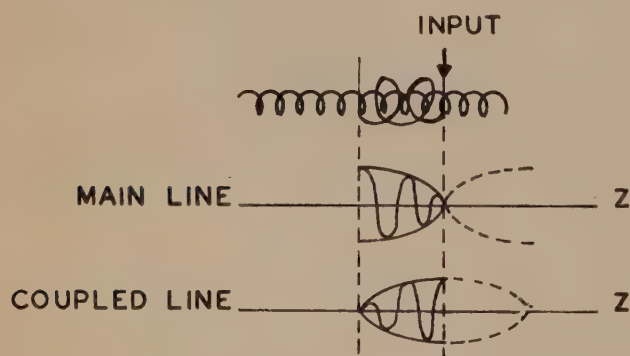


Figure 2 — Diagram of Instantaneous Current on Two Helices

### III. Determination of Dimensions for the Phase Shifter

The important dimensions in designing a helical phase shifter are the pitch, the size of the wire, and the diameters of the helices. To obtain these dimensions for the VHF phase shifter described below, a delay factor of 14 was used as a starting point. This was not an arbitrary choice,

but one based on considerations outlined by Stark.<sup>4</sup> This delay factor is the ratio of the velocity of light to that of the phase velocity on the helix, and is also equal to the ratio of the circumference to the pitch of the helix. In the model described here, the helix had a circumference of 10.84 inches; therefore, in keeping with the choice of 14 for delay factor, the pitch of the helix was 0.774 inch.

The next parameter considered was the wire diameter. Calculations by Peters, et al,<sup>5</sup> show that for least attenuation the ratio of the wire size diameter to the pitch should be equal to 0.33. On this basis, the wire diameter of the inner helix was established as 0.256 inch.

The theory of coupled helices<sup>1</sup> shows that the beat wavelength is stationary with respect to frequency, if the correct choice of geometrical parameters is made. To obtain stationary beat wavelength, the radius of the coupling (outer) helix should be approximately 1.5 times that of the inner helix. It is important to note that stationary beat wavelength also occurs when  $\beta(a_2 - a_1) = 1$ , where  $\beta$  is the uncoupled phase constant which is assumed to have the same value for both helices. Therefore, using the ratio of  $a_2/a_1 = 1.5$ , and  $\beta_1 = \beta_2$  as a first approximation, it is possible to obtain the following dimensions:

Outer helix diameter = 5.15 inches (O.D.),

Circumference of outer helix =  $\pi D = 16.2$  inches

$$\tau (\text{pitch}) = \frac{\text{circumference}}{14} = 1.16 \text{ inches,}$$

and

Diameter of wire =  $(0.33)(1.16) = 0.383$  inch.

Up to this point no account had been taken of the effects of the shield around the outer helix; therefore, the next step was to calculate the phase velocity of the shielded outer helix with the formulas developed by H. S. Kirchbaum:<sup>6</sup>

$$V_z (\text{phase velocity}) = \frac{\tan \Psi}{\sqrt{\epsilon_0 \epsilon_2}} \sqrt{\frac{F_1}{F_2}}$$

Also

$$F_1 = \left\{ \log_e \frac{R_2}{R_1} - \frac{2\epsilon_2}{\epsilon_1 + \epsilon_2} \right.$$

$$\left. \sin \Psi \log_e \left[ 2 \sin \left( \frac{\pi r}{\tau \cos \Psi} \right) \right] \right\},$$

and

$$F_2 = \frac{1}{2} \left( 1 - \frac{R_1^2}{R_2^2} \right) + \tan^2 \Psi$$

$$\left\{ \log_e \frac{R_2}{R_1} - \frac{1}{\sin \Psi} \log_e \left[ 2 \sin \frac{\pi r}{\tau \cos \Psi} \right] \right\}$$

where

$\epsilon_0 = 8.85 \times 10^{-12}$  farads/meter,

$\epsilon_1 = 2.6\epsilon_0$  polystyrene for center conductor,

$\epsilon_2 = 1\epsilon_0$  air,

$R_2 = 3.250$  inches (This value is the radius of the shield covering the outer helix; it was chosen from impedance considerations.<sup>6</sup>),

$R_1 = 2.200$  inches (measured from center of wire),

$$\Psi = \tan^{-1} \frac{\text{pitch}}{\text{circumference}} = 4.45^\circ,$$

$$\tau = \text{pitch},$$

$$\frac{R_2}{R_1} = 1.46, \quad \frac{R_1^2}{R_2^2} = 0.483,$$

$$\frac{r \text{ (radius of wire)}}{R_1} = 0.0855, \quad \frac{R_1}{\tau \text{ (pitch)}} = 1.895.$$

Solving for  $V_z$ , a phase velocity equal to  $0.179$  times  $10^8$  meters per second was obtained. The delay factor was also calculated and found to be  $16.8$ . As might be expected, the shield over the outer helix caused the phase velocity to decrease. The effects and necessary correction of this change in delay factor are analyzed below.

#### IV. Experimental Justification of Design Parameters

In order to measure the phase velocity of the outer helix experimentally, the outer helix was axially displaced along the inner helix, and the distance between minimums was measured. The outer helix had a measured velocity of  $0.178$  times  $10^8$  meters per second. This value for  $V_z$  agreed to within  $0.56$  percent of the calculated phase velocity, which was  $0.179$  times  $10^8$  meters per second.

To measure the phase velocity on the inner helix, a probe was axially displaced along the outside of the helix, one or two pitch diameters away from it. Because the mismatch was large, a piece of teledeltos, which is current-sensitive, was cut into the shape of an equilateral triangle,  $8$  inches by  $8$  inches by  $8$  inches, and wrapped around the outside of the helix to serve as a matched termination. The positions of minimums were then recorded and the phase velocity was calculated. The inner helix was designed to have a delay factor of  $14$ , which would give a phase velocity of  $0.214$  times  $10^8$  meters per second; however, it was measured to have a delay factor of  $15.5$ , or a phase velocity of  $0.194$  times  $10^8$  meters per second.

Figure 3 illustrates the experimental setup used to measure directivity. The power fed into arm A is substantially transferred to terminal C, and thereby makes the phase shifter a unity transmission device. The amount of power

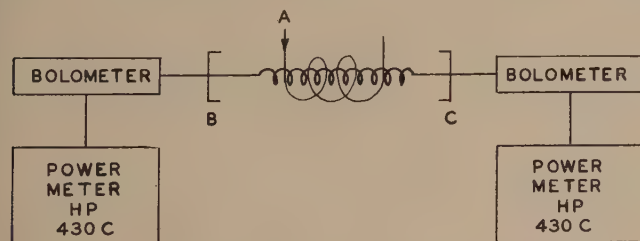


Figure 3—Experimental Setup for Measuring Directivity

transferred depends on the length of the outer helix, which should be a quarter-beat wavelength.

Directivity measurements recorded for the dimensions of the helix showed that the maximum directivity that could be obtained was approximately  $13$  decibels with about  $70$  percent coupling. This meant that all of the power entering at arm A in Figure 3 was not being transferred, and that some power was being reflected back toward terminal B. It was mentioned previously that the two helices had to have

approximately equal phase velocities in order to get maximum transfer of energy. When the values of the phase velocities on the inner and outer helices were checked, it was noted that they were not equal, but differed by approximately  $8$  percent. Therefore, adjustments had to be made to equalize the phase velocities on both helices. The phase velocity on the outer helix was adjusted to match that on the inner helix, which was kept constant. Since the pitch of the outer helix was the easiest dimension to vary, it was altered until approximately equal phase velocities were obtained. They occurred with a pitch of  $0.875$  inch on the outer helix and  $0.774$  inch on the inner helix.

The next step was to find the quarter-beat wavelength necessary for maximum power transfer. The equation for beat wavelength is given in Reference 1: beat wavelength is equal to  $(17.1)$  times  $(a_2 - a_1)$ , where  $a_2$  and  $a_1$  are the radii of the outer and inner helices, respectively. Substituting the values for  $a_2$  and  $a_1$  into this equation, the beat wavelength was recorded as  $14.53$  inches. With a pitch of  $0.875$  inch and a quarter beat wavelength of  $3.63$  inches, the number of turns was equal to  $4.138$ . This meant that with these dimensions, maximum coupling and maximum directivity would be obtained.

The directivity of several outer helices with various numbers of turns was recorded. Maximum directivity and maximum coupling resulted when the number of turns equaled  $4.187$ , which was in close agreement with the theoretical prediction. Using this value for the number of turns, the directivity was in the order of  $40$  db with  $95$  percent coupling (the other  $5$  percent was lost in attenuation and reflection). In order to get values of coupling this high, it was essential that the outer helix be well matched to the coaxial input. A larger percentage of coupling could be had at one position by changing the match at terminals B and C (see Figure 3); but, by introducing this mismatch, the output of B and C would vary as the outer helix was displaced axially. Therefore, to get a constant output level at terminals B and C, the VSWR along the inner helix between points A and B, and A and C, had to be less than  $1.10$ .

By placing a  $50$ -ohm load at the open end of the outer helix, the directivity may be increased by at least  $10$  db. This load absorbs the power which is not transferred and prevents it from reflecting back to terminal B (see Figure 3).

Table I records the results of tests conducted for an inner helix diameter of  $3.44$  inches,  $\frac{1}{4}$  inch copper tubing, with a pitch of  $0.774$  inch, and for an outer helix diameter of  $5.15$  inches,  $\frac{3}{8}$  inch copper tubing, with pitches of  $0.774$ ,  $0.835$ ,  $0.875$ , and  $0.904$  inch. (The diameter of

| Number of turns | Directivity with outer helix pitch (decibels) |           |           |           |
|-----------------|-----------------------------------------------|-----------|-----------|-----------|
|                 | 0.774 in.                                     | 0.835 in. | 0.875 in. | 0.904 in. |
| 3.75            |                                               |           |           | 14.5      |
| 4.0             |                                               |           |           | 14.5      |
| 4.0625          |                                               | 19.6      |           |           |
| 4.125           | 16.0                                          | 21.2      | 35.0      | 14.5      |
| 4.1875          | 17.0                                          |           | 50.0      | 16.5      |
| 4.25            | 16.3                                          | 26.6      | 38.5      | 12.5      |
| 4.5             | 12.5                                          | 15.7      |           |           |

the copper tubing for the outer helix is not the correct one for minimum attenuation with the pitch used; however, since the outer helix is only a short length of line, it was not practical to change this dimension to a non-standard tubing.) The coupling for all test cases was between 90 and 95 percent.

The relationship of directivity to normalized frequency was also measured, and is recorded in Figure 4. In each case the output terminals of the inner helix were matched to the input coax of the outer helix.

## V. Conclusion

The single coupled helix can be extended to a finished device by mechanically ganging two outer helices through a coaxial line. By this means, all output terminals can be stationary. The path between output terminals can be varied by displacing the two coupled outer helices axially along the inner helices to which the output coaxial terminals are attached. Amplitude and phase variations versus displacement can be held to a minimum by correct matching of all coaxial to helix transitions.

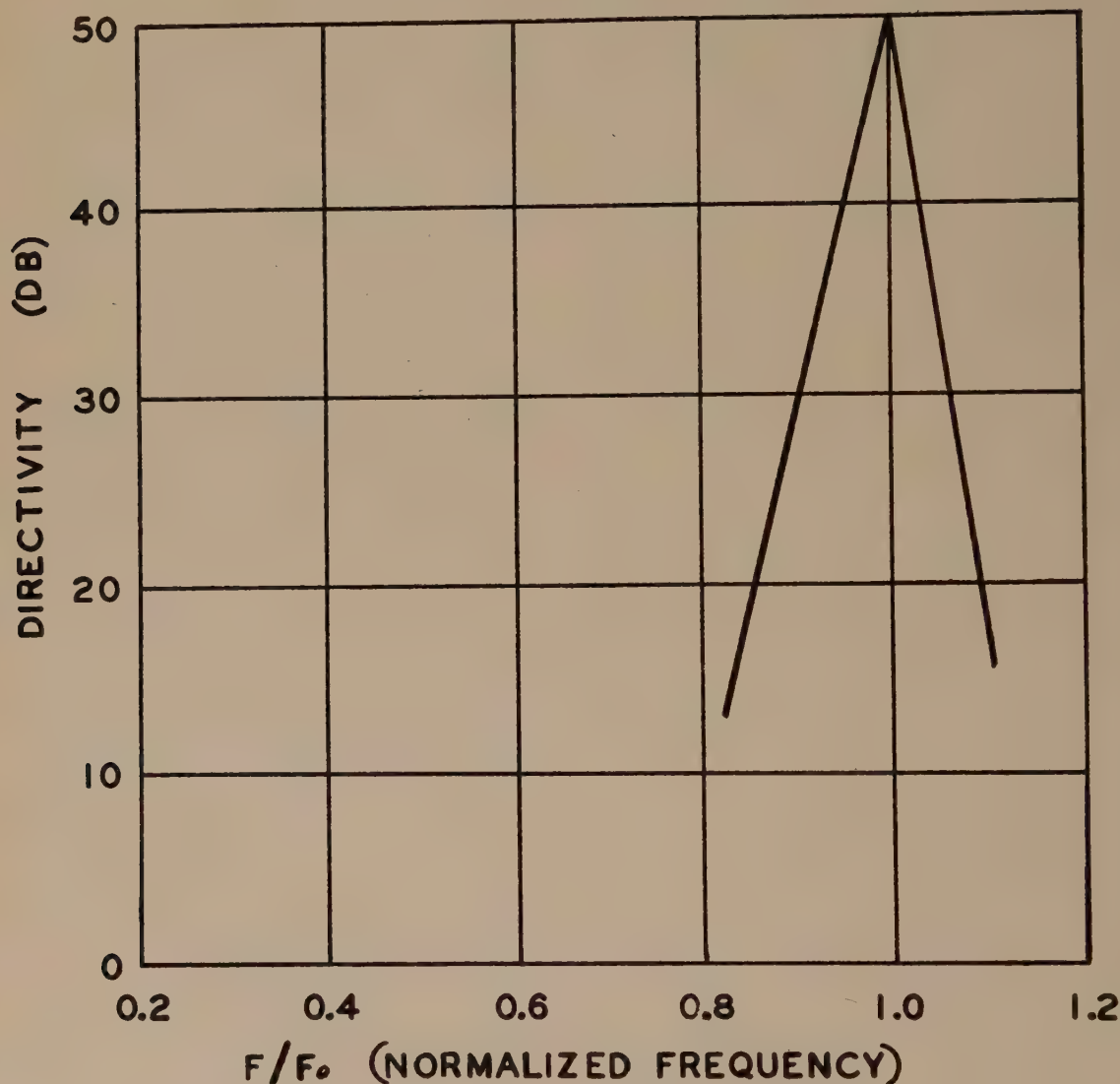


Figure 4—Graph of Directivity vs. Normalized Frequency

## References

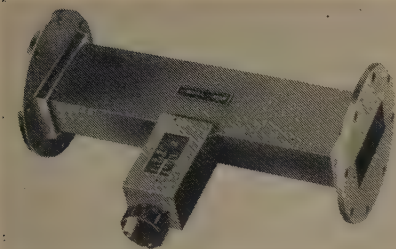
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2. S. Sensiper, *Electromagnetic Wave Propagation on Helical Conductor*, Report No. 194, Research Laboratory for Electronics, May, 1951.
3. J. R. Pierce, *Traveling-Wave Tubes*, New York: D. Van Nostrand Company Inc., 1950.
4. L. Stark, *A Helical-Line Phase Shifter for UHF*, Technical Report No. 59, Lincoln Laboratory, MIT, February, 1954.
5. R. W. Peters, J. A. Rultz, A. B. Olson, "Attenuation of Wire Helices in Dielectric Supports," *RCA Review*, December, 1952, pp. 558-572.
6. H. S. Kirchbaum, *Characteristic Impedance and Phase Velocity of a Shielded Helical Transmission Line*, Report C.I.T. No. 7, Figure 13, Carnegie Institute of Technology.

## Acknowledgments

The authors wish to express gratitude to Mr. Louis Stark for his suggestions in connection with this study. The type of helical phase shifter described is an extension of a device originally developed by him at Lincoln Laboratory and Hughes Aircraft Company.

# NEW PRODUCTS

**POLYTECHNIC RESEARCH &  
DEVELOPMENT CO. INC.  
DIRECT READING LEVEL  
SET ATTENUATORS**



Now available from PRD is a new series of 12 direct reading level set attenuators with frequency ranges from 2.6-3.95 KMC/s, 3.95-5.85 KMC/s, 5.85-8.2 KMC/s, 7.05-10 KMC/s, 8.2-12.4 KMC/s, 12.4-18 KMC/s, a maximum VSWR of 1.15 and featuring accurate attenuation settings by the use of low backlash, multi-gurn drives. Units in each frequency range are available with either 20 or 40 db maximum attenuation.

Each attenuator comprises a section of waveguide containing a resistive vane parallel to the narrow face. The attenuation is increased by moving the metallized plate from the sidewall towards the waveguide center. A scale calibrated near the center frequency of the waveguide range provides direct reading of attenuation.

Featuring minimum leakage; a ruggedized, shock and moisture resistant lossy vane; bilateral matching elements for low VSWR, each unit has an average power dissipation of 1 watt. Insertion length ranges from 2-11/16" through 12"; waveguide dimensions range from .622 x .311 inches for the 12.4-18 KMC/s frequency range units to 3" x 1 1/2" for the 2.6-3.95 KMC/s frequency range units.

CIRCLE READER SERVICE CARD 101

the microwave journal for September/October, 1958

Letters to the Editor

(Continued from page 16)

... heartiest congratulations on the first issue of "the microwave journal." I think you are to be complimented on the quality of the magazine and the excellence of its philosophy. Your editorial staff is particularly outstanding, and I am certain that the material will be of tremendous interest to the industry. . . .

TINY YEWELL  
Yewell Associates  
Burlington, Mass.

... Having just perused Vol. I, No. 1 of your excellent publication, I would greatly appreciate being placed on your subscription list.

ERNEST E. JOHNSON  
Mech. Design Engineer  
General Electric Co.  
Syracuse 1, N.Y.

... Congratulations on your very well written publication, "the microwave journal." After reading Volume I, I am pleased to say that the journal will prove to be of a great help to the microwave industry. . . .

STANLEY J. ROWINSKI  
Sperry Gyroscope Co.  
Great Neck, N.Y.

... I would like to receive "the microwave journal." I am working in the microwave antenna and ferrite field.

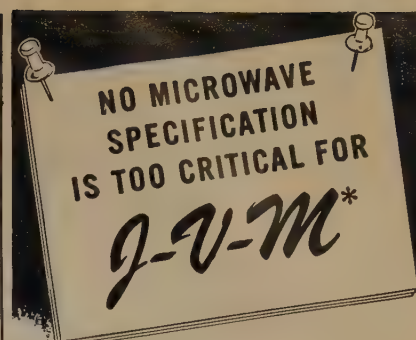
DR. MORRIS L. KALES  
Head, Ferrite Section  
Microwave Antennas &  
Components Branch  
U.S. Naval Research  
Laboratory

... I have found your first issue . . . to be very interesting and informative, and will be looking forward to further publications of such high quality. . . .

RODERICK B. ANDERSON  
Patent Agent  
Bell Telephone Laboratories  
Murray Hill, New Jersey

"As a former microwave spectroscopist, now in maser physics, I was keenly interested in seeing some exclusive attention paid to microwave physics and technology. There is no doubt that your magazine fills a long existing gap in the spectrum of technical publication. . . ."

M. L. STITCH, Head  
Beams and Mm Waves Group  
Atom Physics Department  
Hughes Research Laboratories  
Culver City, California



**\*CUSTOM BUILDERS  
AND DESIGNERS OF:**

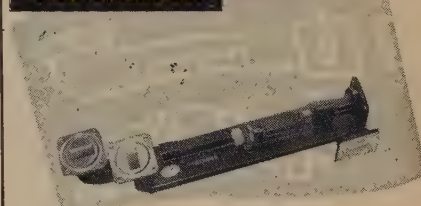
**CAVITIES**

**MIXERS • DETECTOR MOUNTS  
DUPLEXERS • MULTIPLIERS  
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COMPONENTS & ASSEMBLIES**

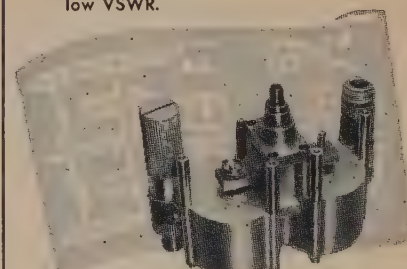
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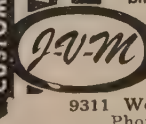
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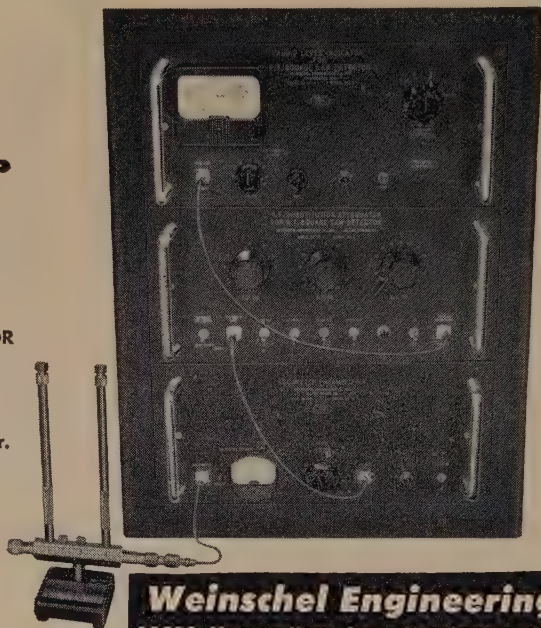
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CIRCLE READER SERVICE CARD 11

## CASCADE OFFERS NEW FERRITE CIRCULATOR

Cascade Research Division of Monogram Precision Industries, Inc., announces the new Cascade Model X442A Ferrite Circulator, covering the frequency band of 8.5 to 9.6 kmc. This device provides the function of transmitting input power from one of the four waveguide terminals to the next in sequence.

Applications include the replacement of a conventional duplexer in a radar system. The new unit isolates the transmitter from the receiver t-r tube by at least 20 db and in most cases 25 db, with antenna reflections only, directed to the t-r tube. In such an application, the at-r tube is eliminated completely.

Giving forward insertion loss of 0.5 db, the Model X442A exhibits a vswr of 1.20 with all arms terminated and is capable of 250 kw peak transmitted power, 250 watts average transmitted power. Operating temperature range is from -55C to +125C.

CIRCLE READER SERVICE CARD 104

## NARDA PUBLISHES NEW CATALOG

A new 84-page catalog describing the company's greatly expanded line of microwave and UHF test equipment and components has just been published by The Narda Microwave Corporation, Mineola, N.Y.

The new 1959 edition of the Narda catalog includes all of the recent additions to the Narda line, in particular the company's new millimeter waveguide instruments for the K to E band, standard gain horns for the 40,000 to 90,000 mc. range, broad band bolometers and thermistors, tuneable waveguide detectors, high directivity directional couplers, coaxial hybrids, tuned pre-amplifiers and transistorized VSWR amplifiers, and laboratory and classroom training sets.

Besides its standard products, Narda is also prepared now to custom-engineer microwave and UHF components for radar and communications systems. Details of this new service as well as a number of typical problems and recommended solutions are given in the new catalog.

CIRCLE READER SERVICE CARD 105

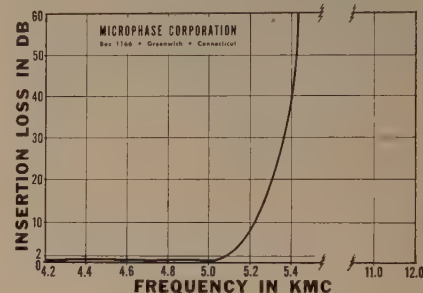
## New Products

### NEW LINE OF RF WAVEGUIDE FILTERS FROM MICROPHASE

Microphase Corporation has just introduced a new line of RF Waveguide Filters featuring very sharp cutoffs and low Insertion Loss in the passbands.

The unit is of the low-pass type cutting off at 5 kmc/s, carefully matched to achieve a maximum loss of only 0.75 db in the passband, with a minimum attenuation of 60 db from 1.08fc out to 12 kmc/s.

This particular unit is designed to



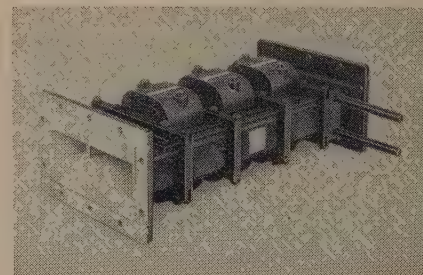
handle up to 100 Watts of power, withstands severe environmental conditions, and is fitted with a UG-149A/U flange at one end and a UG-148B/U at the other. Similar performance can be achieved with units in the S through X Bands. Literature and information are available on request to MICROPHASE CORPORATION, Box 1166, Greenwich, Connecticut.

CIRCLE READER SERVICE CARD 106

### RAYTHEON OFFERS TWO NEW FERRITE DEVICES

An improved version of Raytheon's high-power L-band microwave ferrite isolator has just been introduced.

The new unit, Model 1LH2, is constructed of half-height waveguide to reduce size and weight. It is 6



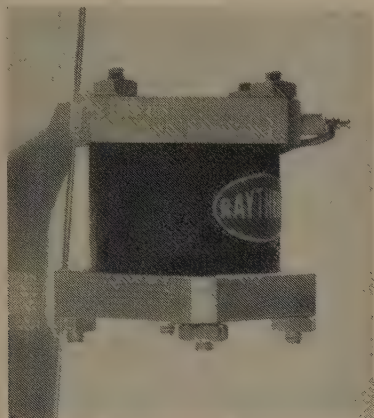
inches high, 8-11/16 inches wide, 17 inches long, and weighs 34 lbs.

Built-in transitions to full-height guide provide match over the entire

band so as to combine high performance with high power capacity. A cooling structure is available for use at higher power levels.

Minimum transmit/receive isolation is 11 db; maximum insertion loss is 0.55 db. Average power handling capacity is 2½ kilowatts, peak power is 3 megawatts.

Also, a low-power X-band ferrite switch has just been introduced by Raytheon for on-off applications.



The unit, Model SXL1, provides a minimum isolation of 25 db with an insertion loss of 0.5 db (maximum). Multiples of this isolation can be obtained by connecting several SXL1's in series.

Weight is only 15 ounces; over-all length, 1.7 inches.

Data sheets are available from Raytheon Manufacturing Company, Special Microwave Device Group, Waltham 54, Massachusetts. Custom engineering is also available.

CIRCLE READER SERVICE CARD 107

### AIRTRON INTRODUCES NEW IMAGE-REJECTION FILTER



An extremely compact Single-Section Dual Mode Filter designed for the microwave journal for September/October, 1958

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This unique electroforming process produces precision, internally-shaped parts, such as this microwave coupler, with internal accuracies and configurations unobtainable or economically prohibitive with any other method.

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integral assembly of unusual accuracy, rigidity, and lightness.

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low power use in X-band systems was introduced recently by Airtron, Inc.

By employing two orthogonal TE<sub>111</sub> modes, this filter provides performance equalling that of a two-section filter.

The tuning range covered is 8500 to 9600 mc/s, with an insertion loss of less than 1.0 db and a VSWR of less than 1.20. Bandwidth to the 3 db points is approximately 20 mc/s at midband. Rejection obtained at Fo ± 60 mc/s is greater than 27 db.

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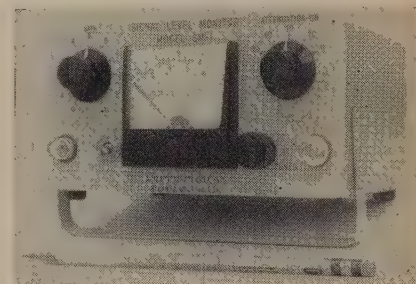
### PORTABLE SIGNAL LEVEL MONITOR BY SCIENTIFIC-ATLANTA

Scientific-Atlanta, Inc., 2162 Piedmont Road, N.E., Atlanta, Georgia, announces their new Model SM-1 Signal Level Monitor.

The S-A Model SM-1 is a portable, light weight instrument designed pri-

marily as a versatile and time saving accessory for antenna and rf laboratories. The SM-1 features high sensitivity, operation with either cw or modulated rf signals, tuned or untuned selective amplifier, no dc drift, precision attenuators and small size.

Applications include: A portable indicator for field strength measure-



ments, an indicator for slotted line signal measurements, ac, dc, or rf bridge null indication, an indicator for optimizing antenna adjustment or orientation, and a versatile laboratory instrument for indicating any ac, dc, or rf signal level.

CIRCLE READER SERVICE CARD 109

# THE F-R STORY

By DAVE SIMON

## BOX SCORE

**NAME:** F-R Machine Works, Inc. (Trademark — FXR)

**LOCATION:** 26-12 Borough Place, Woodside 77, New York

**PRODUCTS:** Microwave instrumentation and plumbing; high power modulators; radar components; X-ray specialties

**HIGHLIGHTS:** This rapidly expanding 14-year old company has made its mark in the microwave field by applying manufacturing techniques of the precision machinist. Booming business has necessitated a 25,000 square foot plant expansion, now being completed.



Management Meeting (left to right): Arthur Stephan, Felix Feldmann, John Wendt, Henry Feldmann, James Ross, Willie Ramhofer, William Marshall.

**A** LONG, LOW group of interconnecting buildings in Woodside, Long Island, just beyond the shadows of Manhattan's towers, houses the F-R Machine Works, Inc. This firm is another example of the vitality and growth that characterizes the microwave industry today. As if to add emphases to this concept of growth, an impressive new plant addition now nearing completion will increase the 75,000 square feet of production space now available by more than 25 per cent.

### From Machine Shop to Microwaves

The history of the company is typical of many in the industry. A modest start in a small building was made in

1944 under the direction of Mr. Henry Feldmann, who to this day personally supervises all operations of the F-R Machine Works. With Willie Ramhofer and Felix Feldmann, he organized the company to subcontract precise machine work from various manufacturers, and composed its name from the initials of the founders. (Probably more familiar to the industry is the trade mark FXR, which identifies all of the company's equipment.)

Henry Feldmann came to the United States from Germany in 1927. In the "old country," he had served a rigid apprenticeship in toolmaking, and in the years between 1918 and 1927, he was plant superintendent in one of

\*EDITOR'S NOTE: This is the second in a continuing series of articles describing firms working in the microwave field. It is our intention to emphasize those aspects of greatest interest to the microwave engineer — products, facilities, size, capabilities, and so forth.

The box score will summarize some of the key items contained in the article.

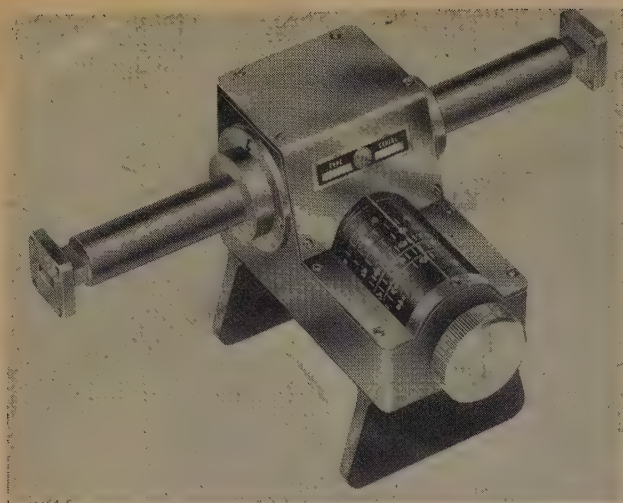
In order to assure that we provide the kind of information which will be most beneficial, your comments and suggestions are welcomed.



Engineering Meeting (left to right): John Ebert, Felix Feldmann, Henry Feldmann, Charles Zavales, Charles Passannante.



Production Meeting (left to right): John Wendt, George Neubert, Henry Feldmann, Felix Feldmann, Joe Jedlica, James Ross, Willie Ramhofer.



A typical microwave product: Direct Reading Precision Variable Attenuator.

Germany's leading industrial firms. Once in this country, he assumed a supervisory position with Westinghouse Electric & Manufacturing Company.

It is significant that when he organized his own company, one of its first subcontracting customers was Westinghouse.

The contributions of Willie Ramhofer and Felix Feldmann have been major ones from the first. Their individual abilities and their combined knowledge of machine building and their combined knowledge of electronic techniques and machine shop operations, based on years of previous experience, have proven a valuable asset to the company.

From 1944, the story of the company is one of steady growth, with people and facilities added as business warranted. Beginning with six when the company started, it has swelled to over four hundred, with more to be added soon.

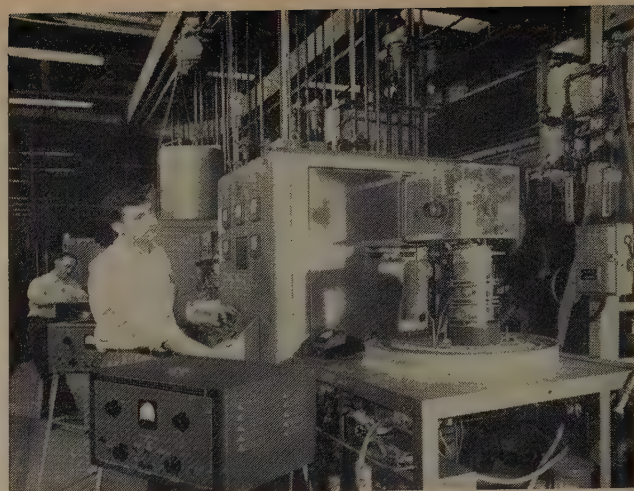
The unique contribution of FXR activities combines a blend of new world engineering and old world craftsmanship. From the beginning, the electronic branch of this work led to the subcontracting of precision equipment for electronic and microwave firms. In 1954, FXR brought out its own line of microwave products. This has become so important that Bill Marshall, the busy Sales Manager of the firm, disclosed that the name "F-R Machine Works, Inc." is regarded as somewhat of a misnomer, and company plans to drop the "Machine Works" have now been completed. The new name, effective January 1, 1959, is **FXR, INC.**

#### Precision Machines for Quality Products

FXR is completely equipped to develop its products from the drawing board to the formed, machined, plated, painted, tested, and packaged unit, ready for delivery. The company has one of the most completely diversified machine shops in the microwave industry today: typical of the equipment is a precision jig-borer, capable of tolerances of better than one ten-thousandth of an inch. Microwave and electronic testing equipment is available in quantities and types too numerous to mention; much of this was designed and produced by FXR to meet its own special needs.

#### The Products (Microwave and X-Ray)

Although X-ray equipment was one of the first com-



A High Power Modulator under test.

mercial items produced by FXR, it is now dwarfed by the microwave products and subcontracting functions of the company.

Most important of FXR's microwave products is a very complete line of test instrumentation. The extensive line, covering the range from 350 mc to 300 kmc, includes microwave power supplies, spectrum analyzers, direct reading frequency meters, and similar equipment.

Old hands at the company recall the first microwave business, which came from MIT—an order for microwave test equipment. Later work was done for Bell Labs and Western Electric on the forerunner of the Nike missile. Indicative of their outstanding achievements in the field, the company was commended in connection with a crash program for DEWLINE. For this project, Bell required the design of microwave signal generators with unheard-of accuracies. FXR not only completed production in seven months, but delivered units that bettered the specified accuracies.

Success in the test equipment line is indicated by FXR's seventy percent increase in sales in 1957, putting them over the two million dollar mark in this field alone and reaffirming their position as one of the leaders. As Mr. Marshall comments, "We don't make every type and size, but we make more types and sizes than anyone else."

Currently, it is the high power pulse modulators and power supplies, which are setting the growth pace for the company. A variety of standard and "custom tailored" units are available ranging in peak power from a few kilowatts all the way up to 80 megawatts, for use with some of the most advanced magnetrons and klystrons. In addition, work is nearly completed on a modulator with an average power of 650 kilowatts!

It was the sky-rocketing sales volume on these units that brought FXR management to the conclusion that more space would soon be needed. As a result, the plant expansion now underway will add 25,000 square feet to the existing production area. Most of the new addition will be used for the design and manufacture of pulse modulators, and the company expects that even the record 100 percent increase in orders now being placed will be greatly exceeded in the future.

Through years in the microwave components field, FXR has built up an enviable degree of skill in the design and



Sales Meeting (left to right): Neal Deoul, Arthur Chasen, Henry Feldmann, William Marshall.

manufacture of switches, rotary joints, TR cavities, oscillators, directional couplers, duplexers, and other hardware. Because it has retained the versatility it had when it was just a small job shop, the company is equipped to build components to customers' specifications, or develop a completely new design if one is required.

### People

The great increase in activities brought about the need for a strong sales force; and, consequently, Bill Marshall, who had been with the company since its inception, was named Sales Manager. A native Australian, Bill was formerly an officer for the Royal Australian Army, responsible for the machine tool acquisition.

Neal Deoul, Head of the Sales Engineering Department, is a graduate engineer with a B.S. in Physics, and will receive his law degree in June. As Sales Head of the expanding commercial equipment operation, Mr. Deoul points out that FXR recently set up a full-time resident sales engineer in the Boston area, so that service and engineering assistance can be directly offered to FXR customers in that busy microwave region.

Chief Microwave Engineer is John Ebert, who is in charge of the design of microwave test equipment and radar components. Mr. Ebert has a B.E.E. degree from Brooklyn Polytechnic Institute. He is hard at work improving and expanding the already impressive line of products.

Charles T. Zavales, Chief Electrical Engineer, is in charge of the design and development of High Power Pulse Modulators. Mr. Zavales has a B.E.E. degree from C.C.N.Y. and has been with FXR since 1948.

Responsible for all mechanical design in microwave systems and components is Charles A. Passannante, Chief Mechanical Engineer, who has a B.S. degree in Aeronautical Engineering from the University of Alabama.

Jim Ross, Production Manager, has been with the firm since 1950. He had previously been associated with Western Electric Company for eleven years, mainly in a supervisory capacity. The success of the production phase of the FXR operation is due in no small measure to the activities of Mr. Ross and the Production Coordinator, John Wendt.

Arthur Stevens, Treasurer of the company, points out that the employees share in an unusual profit-sharing plan. This profit-sharing plan distributes 25 percent of the company's gross profits before taxes to the employees. Each individual's share is determined by his gross income and seniority. This profit-sharing plan augments a general salary level which plant officials say is among the leaders in the field.

Eye on the Future

### Eye on the Future

FXR's formula of putting the skills of able machinists to work in the microwave field has paid off handsomely, as the company's rapid expansion proves. The 70 percent increase in instrumentation business, the 100 percent rise in the sale of modulators, the large plant expansion, are all indicators of the acceptance industry has accorded to FXR's quality equipment. But company management is already making plans for new fields to conquer in the immediate future. Present plans indicate that the next step will be in the direction of microwave systems. Even though F-R, Inc. is presently a closed corporation, who knows what the future holds. No matter how things develop, if the past is any indication, "progress" will be the watchword at Woodside for a long time to come.

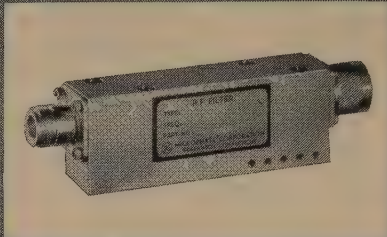
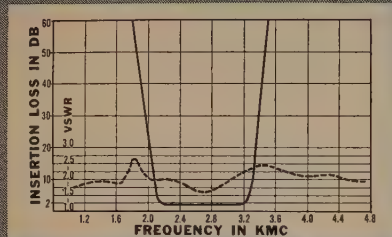
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Similar low-, high-, and bandpass units are available from VHF through X-Band frequencies. Write for literature



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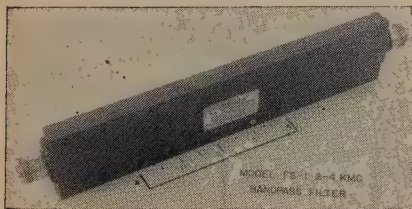
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CIRCLE READER SERVICE CARD 1

## MICROWAVE ENGINEERING LABORATORIES OFFER NEW 2-4 KMC BANDPASS FILTER

The MELabs Model FS-1 2-4 Kmc Bandpass filter is the first of a series of octave bandwidth bandpass filters designed for use in microwave measurements and systems.



The unit has less than 1 db insertion loss in the pass band, rising to 50 db loss at 1.6 Kmc and 4.6 Kmc. The rejection band provides a minimum of 50 db attenuation down to dc and up through X band. The filter is 10½ inches long, 2 inches wide, one-half inch thick, and has female Type N connectors. This unit is one of a series of octave and waveguide bandwidth filters covering 0.5 to 40 Kmc. For information and data sheets write: Microwave Engineering Laboratories, Inc., 943 Industrial Avenue, Palo Alto, California.



## RADAR DESIGN CORP. OFFERS COAXIAL NOISE SOURCE

Radar Design Corporation, Syracuse, N.Y., announces the addition to its line of a complete noise source of known value to cover the entire frequency range 250 megacycles through 2500 megacycles.

The complete noise source package consists of a power supply and a noise source mounting type N input and output connectors.

Specifications are:

VSWR: Below 1.3

Excess noise power ratio:

16.4DB + 0.3DB

## NEW PRODUCTS

### HIGH POWER PULSE MODULATOR BY MANSON LABS

A recent addition to their line of pulse modulators is Manson Laboratories' Model 270, an 18 megawatt line-type pulser designed to prove out and test high powered magnetrons. The equipment delivers a peak pulse voltage of 100 kilovolts into a 550-ohm load. Peak pulse current is 180 amperes. Pulse widths of 2, 4 and 6 microseconds are available at a maximum duty cycle of .001. Repetition rates are internally controllable by means of an audio oscillator, with provision included for setting of frequency from external sine or trigger source.



The modulator employs a 1257 thyatron, grid-driven by a hard-tube trigger generator, in a conventional line-type pulse circuit. Included in the set is a 900 watt filament supply for the tube under test. Meters for all pertinent voltages and currents are incorporated, as are monitoring circuits for observing output pulse voltage, output pulse current and grid-drive to thyatron.

The power supply, which is rated at 18 KVDC @ 1.25 amps, is housed in a separate cabinet, and mutually interlocked with the modulator. The supply is also usable separately, without energizing the modulator circuitry.

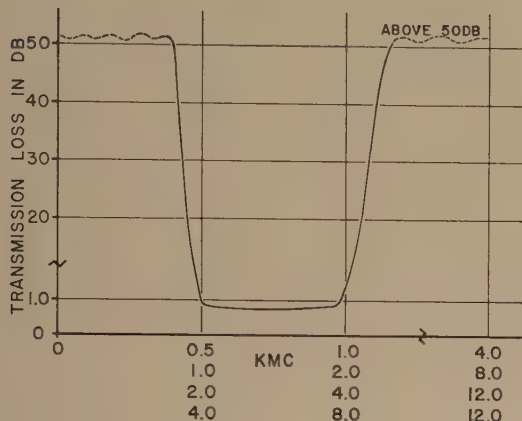
Details are available on this and other high power modulators from MANSON LABORATORIES, INC., Dept. MJ, P.O. Box 594, 207 Greenwich Ave., Stamford, Conn.

This noise package was developed to facilitate the development and testing of receivers, amplifiers, etc., operating in the large number of commercial and military bands contained

# MELabs announces:

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FOR ELIMINATING SPURIOUS OUTPUTS OF  
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Characteristics are:

| Model | Bandpass Frequency | Approximate Size-inches |
|-------|--------------------|-------------------------|
| FU-1  | 0.5-1              | 5 x 21                  |
| FL-1  | 1-2                | 2½ x 18                 |
| FS-1  | 2-4                | 2 x 12                  |
| FC-1  | 4-8                | 1½ x 6                  |

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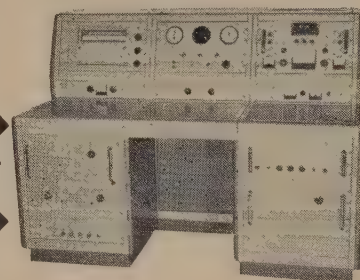
Control Unit for Antenna  
Positioner or Model Tower.

Model 402C Wide Range  
Receiving System covers  
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without  
plug-in  
units. An-  
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be located  
up to 75  
feet away.

Model 121B3  
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arithmic and  
square root  
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Model 122B  
Polar Recorder  
may be in-  
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Model 301R  
Signal Source  
Remote Tuning  
Unit.



The stand-  
ard S-A  
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corders plot  
a graph

linear in db over a 40 db  
range. The extended range of  
the new system is obtained  
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# VSWR Nomograph

by

Gershon Wheeler

SYLVANIA ELECTRIC PRODUCTS CO. INC.

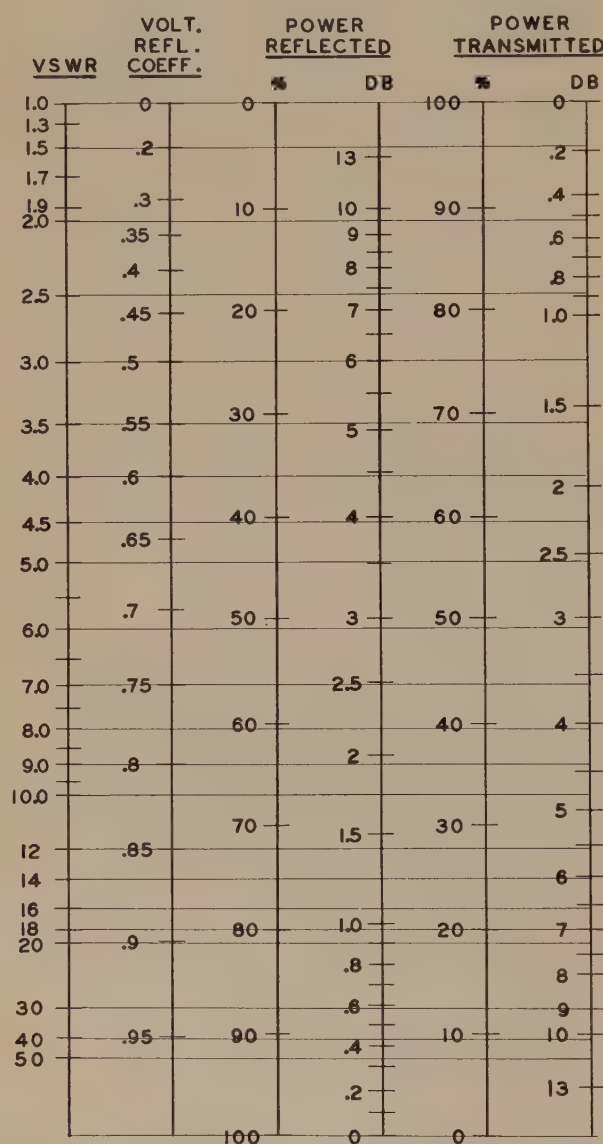


Figure 1

In this nomograph there are six vertical lines. The first is VSWR; the second voltage reflection coefficient; the third and fourth represent power reflected as a percentage of input power and in db down from incident; the fifth and sixth represent power transmitted, also as a percentage of input power and in db down from incident. All equivalences are horizontal. Thus, to find the values corresponding to a VSWR of 4, one proceeds horizontally from 4 in the first column of figure 1. This corresponds to a reflection coefficient of 0.6 (column two), a power reflection 36% of incident and slightly less than 4.5 db down from incident, a power transmission 64% of incident which is about 1.9 db down.

Figure 2 is a magnification of the top tenth of figure 1, and figure 3 is a magnification of the top tenth of figure 2. Thus the charts may be used with accuracy for low as well as high reflections.

Besides the obvious use in finding equivalent values of VSWR and reflection coefficients, the charts may be used to simplify a number of calculations. A few of these are illustrated:

1. If a load VSWR is 2.5 to 1, what sort of pad will bring it down to 1.2 to 1? This is done by noting first that a 2.5 mismatch corresponds to a power reflection down 7.4 db. From figure 3, it is noted that a 1.2 mismatch corresponds to 20.9 db down in reflection. Thus somehow the difference or 13.5 db must be added in the line to bring 2.5 down to 1.2.

This might be done with a resistive pad of half of this value or 6.8 db (since it attenuates in both directions), or it might be done with a ferrite isolator whose total isolation and insertion loss equaled 13.5 db.

2. In a matched 7 db directional coupler, how much is the signal in the main line attenuated? Here it may be assumed that the 7 db signal removed from the main signal will reduce it the same amount as if it were caused by a reflection. Hence, the problem may be solved by noting on figure 1 that a power reflected 7 db down corresponds to a power transmitted about 0.96 db down. It may also be noted that 7 db reflected means 20% power reflected (or coupled) and 80% transmitted.

| VSWR | VOLT.<br>REFL.<br>COEFF. | POWER<br>REFLECTED |    | POWER<br>TRANSMITTED |     |
|------|--------------------------|--------------------|----|----------------------|-----|
|      |                          | %                  | DB | %                    | DB  |
| 1.0  | 0                        | 0                  | 30 | 100                  | 0   |
| 1.1  | .05                      |                    | 24 |                      |     |
|      |                          |                    | 22 |                      |     |
| 1.2  | .10                      | 1                  | 20 | 99                   | .05 |
|      |                          |                    | 19 |                      |     |
| 1.3  |                          |                    | 18 |                      |     |
|      | .15                      | 2                  | 17 | 98                   | .10 |
|      |                          |                    | 16 |                      |     |
| 1.4  |                          | 3                  | 15 | 97                   |     |
|      |                          |                    | 14 |                      |     |
| 1.5  | .20                      | 4                  | 14 | 96                   |     |
|      |                          |                    |    |                      | .20 |
|      |                          | 5                  | 13 | 95                   |     |
| 1.6  |                          |                    |    |                      |     |
|      | .25                      | 6                  | 12 | 94                   |     |
|      |                          |                    |    |                      | .30 |
| 1.7  |                          | 7                  |    | 93                   |     |
|      |                          |                    |    |                      |     |
|      |                          | 8                  | 11 | 92                   |     |
| 1.8  |                          |                    |    |                      | .40 |
|      | .30                      | 9                  |    | 91                   |     |
| 1.9  |                          |                    |    |                      |     |
|      |                          | 10                 | 10 | 90                   |     |

Figure 2

| VSWR | VOLT.<br>REFL.<br>COEFF. | POWER<br>REFLECTED |    | POWER<br>TRANSMITTED |      |
|------|--------------------------|--------------------|----|----------------------|------|
|      |                          | %                  | DB | %                    | DB   |
| 1.01 | .005                     | 0                  | 45 | 100                  | 0    |
| 1.03 | .015                     |                    | 35 |                      |      |
|      |                          |                    | 33 |                      | .002 |
| 1.05 | .025                     |                    | 31 |                      |      |
|      | .030                     | .1                 | 30 | 99.9                 | .004 |
| 1.07 | .035                     |                    | 29 |                      | .006 |
| 1.08 | .040                     |                    | 28 |                      |      |
| 1.09 | .045                     | .2                 | 27 | 99.8                 | .008 |
| 1.10 | .050                     |                    | 26 |                      | .010 |
| 1.11 | .055                     | .3                 | 25 | 99.7                 |      |
| 1.12 | .060                     |                    |    |                      | .015 |
| 1.13 |                          | .4                 | 24 | 99.6                 |      |
| 1.14 | .065                     |                    |    |                      | .020 |
| 1.15 | .070                     | .5                 | 23 | 99.5                 |      |
| 1.16 | .075                     |                    |    |                      | .025 |
| 1.17 | .080                     | .6                 | 22 | 99.4                 |      |
| 1.18 | .085                     | .7                 |    | 99.3                 | .030 |
| 1.19 |                          |                    |    |                      |      |
|      | .090                     | .8                 | 21 | 99.2                 | .035 |
| 1.20 |                          |                    |    |                      |      |
| 1.21 | .095                     | .9                 |    | 99.1                 | .040 |
| 1.22 | .100                     | 1.0                | 20 | 99.0                 |      |

Figure 3

UPCOMING — NEREM —  
NOVEMBER 19-20, 1958

The Northeast Electronics Research and Engineering Meeting will be held at Mechanics Hall, Boston, Mass., on Wednesday and Thursday, November 19 and 20, 1958. The times of the sessions will be from 9:00 a.m. to 10:00 p.m. on Wednesday, and from 9:00 a.m. to 6:00 p.m. on Thursday. The meeting will close with an industry cocktail party on Thursday evening.

This meeting is sponsored jointly by the Boston, Connecticut and Western Massachusetts Sections of the IRE.

The theme of this year's meeting will be "Today's Electronic Developments — Tools For Tomorrow," and an excellent program of technical papers based on this theme will be offered.

Two hundred exhibits will be shown in the Exhibition Hall, and attendance is expected to exceed the more than 5000 who visited last year's meeting.

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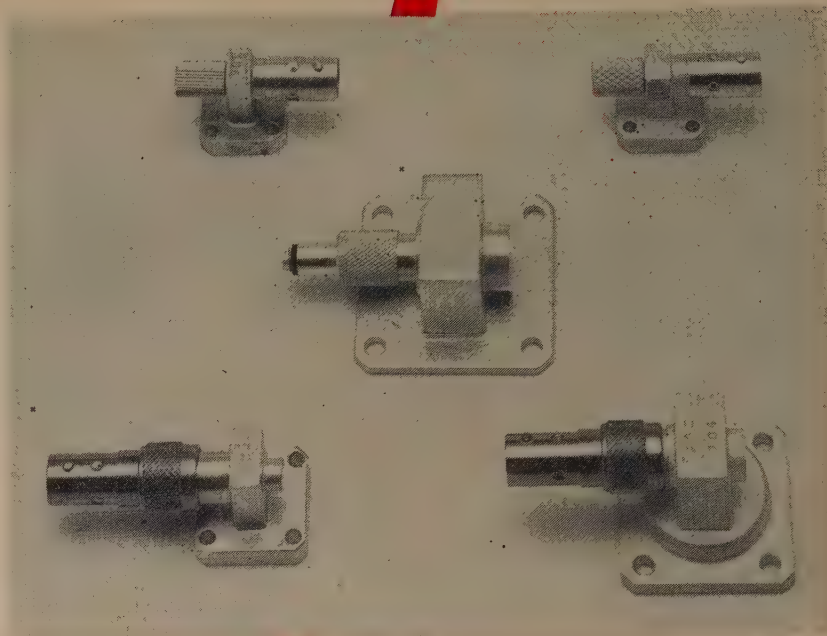
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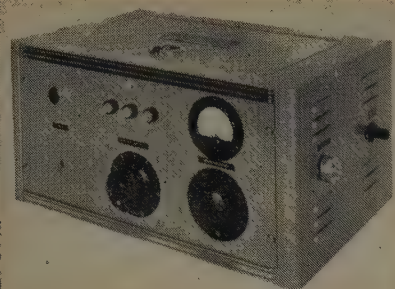
WELLESLEY 81, MASS.

CIRCLE READER SERVICE CARD 18

the microwave journal for September/October, 1958

## NEW PRODUCTS

### MANSON OFFERS NEW LOW RIPPLE MAGNET SUPPLY



Usable as a magnet supply for high power traveling wave tubes, or as a medium-power general purpose laboratory supply, the new Manson Laboratories' Model M25 Power Supply provides the following:

Output: 0 to 250 volts DC @ 10 amperes.

Ripple: 0.5% peak to peak.

Load Protection: Undercurrent relay adjustable from 1 to 10 amps for removing power from external circuits when magnet current falls below preset value.

Input: 208V, 3 phase, 60 cps, 2.7 KVA.

Dimensions: 21½" W x 15" D x 10½" H.

Weight: 50 pounds.

Other features include: The use of silicon rectifiers; an output current meter; a polarized twist-lock male output connector; a shorting plug for undercurrent interlock connector; and a 10-foot, 4-wire power cord with male and female connectors.

The complete unit is priced at \$395.

A descriptive bulletin is available upon request from MANSON LABORATORIES, INC., Dept. MJ, P.O. Box 594, 207 Greenwich Ave., Stamford, Conn.

CIRCLE READER SERVICE CARD 113

### WEINSCHEL ENGINEERING OFFERS NEW SC 50 OHM COAXIAL TERMINATIONS

Weinschel Engineering of Kensington, Maryland has a new Coax Termination. The new SC 50 has a frequency range which is from D.C. to 10 KMC with SC male and female connectors. The specifications are described below.

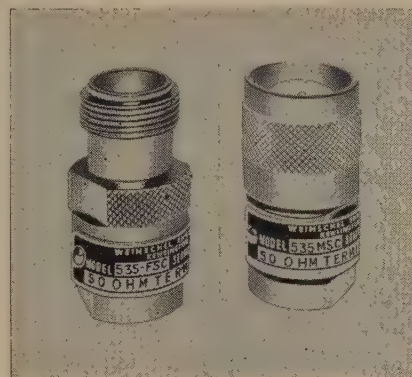
Frequency Range: D.C. to 10 KMC  
Maximum Input Power: 1 watt average, 1 KW peak (at pulse lengths not exceeding 5 microseconds)

D.C. Resistance: 50 + 1 ohm at 25°C

Load Resistor: Artificially aged

Temperature Coefficient of Resistor: 0.03%/°C

Excellent shock and vibration resistance; negligible change of VSWR under humidity and temperature cycling.



| Model Number | Mates With | Maximum VSWR In 50 Ohm System |
|--------------|------------|-------------------------------|
| 535 MSC Male | DIC 2412   | D.C. to 1 KMC 1.10            |

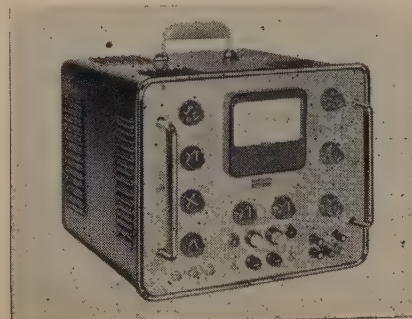
|             |      |
|-------------|------|
| 1 to 4 KMC  | 1.15 |
| 4 to 10 KMC | 1.30 |

|                |          |                    |
|----------------|----------|--------------------|
| 535 FSC Female | DIC 2413 | D.C. to 1 KMC 1.10 |
|----------------|----------|--------------------|

|             |      |
|-------------|------|
| 1 to 4 KMC  | 1.15 |
| 4 to 10 KMC | 1.30 |

CIRCLE READER SERVICE CARD 114

### NEW FXR KLYSTRON POWER SUPPLY



## Microwave Engineers

Engineers wanted with two to eight years experience in designing microwave components and instruments.

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FXR's new Z819A Klystron Power Supply is a compact versatile unit designed for low and medium power klystron tubes. Beam voltages up to 1000 volts at 85 mils, reflector voltages up to 900 volts and a —300 to +150 volt grid supply are available. All voltages may be accurately pre-set. In addition, important voltages and currents are front-panel metered. Other features include sawtooth, square wave and pulse modulation, minimum ripple on all supplies, switch selected fuses to protect the klystron from damage due to overload, and a fine control allowing precise reflector voltage settings.

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## CANOGA MERGES WITH UNDERWOOD

The merger, in July, 1958, of the Canoga Corporation of California with the Underwood Corporation, is another business transaction that points up the growth, vitality and movement within our microwave industry.

It is Underwood's plan to use Canoga to spearhead its defense products interests. According to Mr. George E. Hewitt, Executive Vice-President and General Manager of Canoga, the volume of the Canoga Division will run approximately \$3 million this year. Mr. Frank Beane, President of Underwood, has estimated that the profit will earn about \$0.40 per share of Underwood stock. It is expected that the Canoga Division will, in addition to the wide variety of fields with which it has been identified in the past, work closely with Underwood in connection with computers and data handling.

Canoga was formed as a California Corporation about ten years ago by six working stockholders and several outside investors who were friends of theirs. In those ten years Canoga grew to approximately 200 employees, with 29,000 square feet of floor space in Van Nuys, California, as well as 4,500 square feet in Fort Walton Beach, Florida, near Eglin Air Force Base.

The first contract awards to the young corporation were for new radar antennas, receivers, duplexers and transmitters, and much of the business done by the firm in the early days was the design and manufacture of units to improve the performance of existing radar systems. The firms interests gradually branched out to include test equipment and other electronic and electro-mechanical equipment; and in the past five years Canoga has become greatly involved in the guided missile range instrumentation program.

Of the original six working stockholders, three remain with the firm. These are Paul H. Ryckoff, President; George E. Hewitt, Vice-President and General Manager, and George H. Nibbe, Vice-President, Special Products Engineering.

Three separate engineering departments make up the organization, headed by Joe G. McCann, Chief

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Engineer: Microwave and Antenna Engineering, headed by Robert J. Stegen; Electronic Engineering, under Edward J. Farley, and Mechanical Engineering, guided by William Falstrom.

# The Microwave Instrument Industry

By WILLIAM A. BOURKE  
EXECUTIVE VICE-PRESIDENT  
NARDA MICROWAVE CORP.  
MINEOLA, LONG ISLAND, N.Y.



Bill Bourke is a native New Yorker. His study of marine engineering at Webb Institute of Naval Architecture was terminated by World War II. Three years in the Army including schooling at the University of Pittsburgh and Fort Monmouth, plus communication assignments in the Philippines and Japan, switched his interests to electronics. After the war he attended Carnegie Tech and was graduated in 1948 with a BSEE. He was employed by Sperry as a project engineer on microwave instruments and components until early 1953. Since then he has been associated with Narda. In addition to his general administrative functions his primary responsibilities have been sales and marketing for The Narda Microwave Corporation. Bill is a senior member of IRE, the professional groups PGMTT, PGANE, PGI, PGUE, Tau Beta Pi, Eta Kappa Nu, and Omicron Delta Kappa. Other achievements include six children aged one month to ten years.

**T**HE MICROWAVE INSTRUMENT INDUSTRY must be considered as a segment of the Microwave Industry and also a segment of the Electronic Instrument Industry. From the engineering and production point of view, microwave instruments are an extension and corollary to all microwave work. From the management and sales point of view, they are simply another type of electronic instrument and to be treated as such. Let us take a look at this young and vital field of microwave instruments. We would define microwave instruments as encompassing all tools and measuring devices used in making measurements in the frequency range from 1,000 to 300,000 megacycles. Under this definition, we would include such items as complex multihead spectrum analyzers costing thousands of dollars, slotted lines and directional couplers costing a few hundred dollars, waveguide to coaxial adapters costing about \$25, and \$10 bolometers. This is the equipment our microwave engineer must use in his engineering and development work and in the production testing of his finished microwave system and its components. It should be recognized that there is often no clear cut distinction in microwaves between an instrument and a component. A directional coupler, for example, may be purchased as a measuring and calibration device for testing

the microwave journal for September/October, 1958

attenuators. This same coupler may later be incorporated in a radar system to provide a sample of the transmitted power for AFC action. Many other types of microwave "instruments" are often used as components, including adapters, terminations, detectors, tuners, slotted lines and frequency meters.

Microwave instruments have only recently become a recognizably separate segment of the industry. In the late 1930's and early 1940's, the microwave industry was growing and expanding phenomenally and operating without any catalogs of instruments and test equipment. Microwave instruments were often improvised, frequently with a great deal of ingenuity and often, by today's standards, quite crude. People with microwave system problems generally also had the problem of designing their own microwave test equipment. Many of us in the microwave industry today can remember the early system contracts on which we worked (especially if they were not in X Band) on which we spent thousands of dollars designing and building slotted lines, adapters, or couplers which couldn't be bought any place or at any price and for which today

# The Microwave Instrument Industry

(Continued from page 47)

we would hesitate to pay more than \$200 or \$300. The microwave instrument industry has come into existence to fill this gap.

After the radiation laboratories consolidated and published the existing know-how on microwave measuring equipment, the first commercially available instruments started to appear. In those days, microwave test equipment was generally an off-shoot of the microwave systems work being done by the large corporations working on radar systems. Their first needs were to fill their own requirements for test equipment, the items often being developed on their government contracts, with an overrun of these same items being made available for sales. As a result, there was no such thing as a complete microwave line and it was very difficult if not impossible to put together a complete measurement setup in any but the most popular radar bands. In fact, most of the equipment was very narrow band and limited to use within small popular frequency ranges. Most of these early items have now practically disappeared from the market and the microwave instruments in widest use today are being produced by smaller companies specializing in microwave instrumentation.

Today, microwave instruments is a competitive industry. None of the major suppliers are large corporations despite the fact that some very significant contributions to the microwave instrument field continue to originate in the research laboratories of some of the largest companies. Of the major suppliers of microwave instruments, one, employing about 1,800, also manufactures a wide variety of other types of electronic instruments but the other three or four, who produce a very wide range of microwave instruments for all the waveguide bands, specialize almost exclusively in microwaves, and none of them employs as many as 500 people. Besides these principal suppliers of waveguide and coaxial instruments, there are several companies specializing in the more complex microwave instruments only such as spectrum analyzers, receivers, and broadband swept signal sources. There are an additional dozen or so companies offering some types of microwave instruments and publishing some form of a microwave catalog.

This microwave instrument industry is something more than a lusty infant today. It is estimated that the catalog item sales amount to about \$40,000,000 annually. Approximately \$10 to \$15 million worth is in waveguides and coaxial products, and the remaining \$20 to \$25 million is in the complex microwave electronic instruments, such as spectrum analyzers and swept signal sources. These figures do not include sale of "plumbing" assemblies by companies in the microwave component field. Microwave instrument sales are expanding at the rate of around 20% each year and no one in the industry expects to see this return decrease with the constantly increasing applications and new techniques.

With at least four prime sources for many microwave

instruments plus additional manufacturers for some items, the microwave engineer today can choose test equipment tailored to suit his requirements and budget. The four major microwave instrument suppliers generally manufacture equipment which is compatible with each others products. There has even been a certain amount of standardization among these companies, and it is possible, for example, to use either the fixed tuned crystal detector probe of one company or the tuneable crystal or bolometer probes as supplied by the other three in all the most widely used makes of waveguide impedance meters (except in the millimeter bands). There is an unfortunate lack of standardization in some areas. For example, in the designation of waveguide bands the band covered by  $1\frac{1}{4} \times \frac{5}{8}$  inch waveguide is designated "H" in one catalog, "XB" in another, and "W" in a third. Happily, corporate individuality has expressed itself in more valuable areas. While each company offers a standard competitive product line, one has achieved particular recognition for pioneering a new type of direct reading attenuator, another for its unique substitute for slotted line type impedance meters in the lower microwave bands, another for its direct reading low priced frequency meters and general adaptation of attractive "modern design" principles to standard products, and a fourth for its introduction of an extensive array of flat, broadband coaxial directional couplers from 200 to 10,000 mcs. These, of course, are less than thumb-nail sketches of these manufacturers and just single instances of their individuality which can be seen in practically every product they market.

Competition, especially for the last few years, has created a healthy situation for the user of microwave instruments. The honorable yet keen competition has spurred the suppliers of microwave instruments to continuously improved specifications, prices, deliveries, and new products. A few years ago waveguide terminations with a VSWR of 1.06 were the best available while today a maximum VSWR of 1.02 is standard. Not so long ago detectors for power measurement had to be tuned for each frequency, while today broadband thermistor mounts covering full waveguide bands are available, with one company offering mounts in which bolometers and thermistors may be used interchangeably without tuning. Micrometer read-outs are rapidly being replaced by direct-reading dials and digital indicators on many products. All four major microwave instrument manufacturers now offer equipment to 40,000 megacycles, and three of them cover all the way to 90,000 megacycles. Each company attempts to maintain a fairly large representation of its products in stock or on short delivery (not an easy task for a product line numbering 600 items). Therefore, although each company has a number of products unique to itself, in many instances a customer may find at least one of the four with the product he needs in stock. This continuing improvement in test equipment performance and cost has made possible many of the advances of the overall microwave industry and we, as microwave instrument manufacturers are proud of the part we have played in the advance of microwaves and the art of electronic instrumentation.

*all the performance . . . half the size!*

L

S

X

C

X<sub>b</sub>

K

K<sub>u</sub>

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